A SERIES OF BOOKS IN AGRICULTURAL SCIENCE

Animal Science

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IMPROVEMENT OF LIVESTOCK PRODUCTION IN WARM CLIMATES

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W. H. FREEMAN AND COMPANY
San Francisco

Printed in the United States of America

International Standard Book Number 0-7167-0825-6

Library of Congress Catalog Card Number 74-170395

1 2 3 4 5 6 7 8 9

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Preface

The overall purpose of this book is to draw attention to some of the factors that reduce the efficiency of livestock production in a region of the world in which it is most vital—the so-called "warm climates" lying between latitudes 30° North and 30° South. High air temperatures and rainfall distribution in this region create conditions which influence the efficiency of performance of livestock directly by affecting the animal's body functions and indirectly by causing fluctuations in feed supplies and increasing the incidence of animal diseases.

This book is intended primarily to serve the needs of students in American universities who are interested in gaining insight into the variety of problems associated with livestock production in the warm climates, American nationals serving in programs for livestock development abroad, and foreign nationals contemplating development of area or country programs for improvement of livestock production.

Though the average performance of animals in the warm climates is low by northern-latitude standards, there are a number of factors that favor the further development of animal production. Among these are: (1) the numerous highly efficient livestock enterprises already established in the region; (2) an increasing demand for livestock products with expanding human population; (3) a continuing need for animals to provide services such as power for agriculture, and non-food products such as wool and hides; (4) the indigenous population's traditional taste for animal products; (5) the importance of animals in soil and water conservation; and (6) the great flexibility that domestic animals show in their capabilities for transforming feeds into products necessary for the most efficient total agricultural produc-

tivity of the region. What has been accomplished in Israel and in the southern part of the state of Louisiana with dairy cows, in Australia with sheep, and in Tanzania and Jordan with poultry shows it is not impossible to have highly productive animal enterprises in the warm climate region. However, it is not simply a question of increasing the total number of animals—this region now has over 50% of the world's cattle, horses, mules, and asses, 75–80% of the goats, buffaloes, and camels, and 30–35% of the swine, sheep, and poultry. Rather, the challenge is to obtain the optimum yield from the total soil-crop-animal environment complex.

Many aspects of animal production have already been extensively studied in the cooler regions of the world, and there appears to be no need to repeat much of this work in the warm climates since characteristics that depend exclusively or predominantly on the genotype of animals will be the same in any environment. The Holstein cow, for example, if bred to the same bull, will produce a black and white offspring in either Colombia or New York State. By contrast, housing for cows in the same two places must be quite different for the animals to obtain anywhere near the same level of performance in as much as the productivity of animals is highly dependent upon environmental conditions. For example, we do not know much yet about the importance of animal genotype environmental interactions in the warm climates.

Much more research is needed in warm climate regions. But the challenges of the immediate future cannot wait. Without adequate research, local livestock producers must continue to apply technology on an empirical basis. Unfortunately, this will have to continue, but fortunately, technology has advanced enough so that with careful preplanning satisfactory decisions can be made on the likeliness of success in changes for livestock production.

A major portion of this text is devoted to pointing out how experiences in the cooler latitudes, as well as in various parts of the warm climates, may be applied on a broader scale with a high probability of success. Firstly, we must dispel the long held concept that livestock production in warm climates entails a set of problems entirely peculiar to the area. This hypothesis was based mainly on the belief that the direct effects of the climate in the region were chiefly responsible for the low level of productivity of animals. Recent research findings, however, strongly indicate that the climate's major detrimental impact is rather through its indirect effect. Thus the inhibitors of livestock production may, in many respects, be common to all latitudes. At the same time we ought to discard some of our romantic notions about approaches to genetic improvement, such as high emphasis on

phenotypic traits that have little economic value. Too, we must cease to over-indulge in the concept that body appendages, possessed by certain types of livestock indigenous to warm climates, like the pendulous dewlap of Zebu cattle, are of great significance in their suitability for most efficient production.

In most of the warm climate region, the swine and poultry industries have developed around advanced technology from the temperate zone. These industries will continue to depend largely upon technological innovations and fate of the area. In contrast, traditional methods are still used in the production of sheep, goats, cattle, and buffaloes, and for this reason the major emphasis is on these species.

It would obviously be impossible in a book of this sort to provide detailed plans that might be followed in a given country because too much depends upon local conditions. The real objectives of this book are to examine some of the basic cause-and-effect relationships and to attempt to explain why certain measures are generally necessary or desirable. The discussions deal principally with the requirements of specialized livestock enterprises rather than small farms, because it is the specialized enterprises that will make most of the significant contributions to additional food supplies. Careful examination of practices on small farms reveals that these are already obtaining from their animals about as much as can be expected. It is pointed out, however, that the output of small farms could be greatly increased if governments were prepared to provide a high input of services.

As this book proceeds from one major principle to the next, it attempts to tie together limited research findings from the warm climate regions and well established principles of animal breeding and other aspects into a general picture to emphasize the simplicity of the underlying factors involved and to illustrate how the two can be used effectively for programs of livestock improvement in the warm climates.

In writing this book I have attempted to be as subjective as possible. I have been somewhat pessimistic about the projected application of experimental findings to farm situations, but as is commonly done, I have indulged in the practice of quoting maximum or near maximum yields—not by choice but because this is what is available—rather than the returns from the application of technology.

While taking sole responsibility for any errors of fact or interpretation in the book, I wish to thank the many friends, colleagues, and students who have helped along the way. Those who generously permitted me to use information from their unpublished works and those who provided photographs to serve as illustrations, I have tried to acknowledge in the text, but I may have failed to mention all. I am

especially indebted to the individuals who contributed the chapters on the sheep of northern Africa and southern Asia, on the buffalo, and on the handling of livestock products I greatly appreciate the assistance of Dr Cecil Branton of Louisiana State University, who made helpful suggestions on the entire manuscript, and of my colleagues at Cornell, Dr P J VanSoest, Dr J T Reid, and Dr J K Loosli, who gave their comments on the chapters dealing with problems of feed production and livestock management. To the many persons who have contributed in these and other ways, I wish to convey my deepest gratitude

August 1972 *R E McDowell*

IMPROVEMENT OF LIVESTOCK PRODUCTION IN WARM CLIMATES

I

FACTORS INFLUENCING LIVESTOCK PRODUCTION IN WARM CLIMATES

1

The Role of Livestock in the Warm Climates

The region of warm climates has been designated as the belt around the earth lying between latitudes 30° North and 30° South (N-S 30°), as shown in Figure 1.1. Much of this region has a characteristic climate that, through its direct and indirect influences, creates certain problems for both crop and animal production. Too, it is a region of rapidly expanding population. In 1966 the population of the region (including more than 70 countries lying entirely within the belt, as well as parts of others, and many islands) was about 2.0 billion—nearly 60% of the world's total. According to the United Nations medium level projections, it will pass the 5-billion mark by the end of this century.

Due to rapid population increase much of the region is deficient, or nearly so, in total food production. Though the region contains about one-half of the world's potentially arable land, it produces only about one-third of the world's total cereal grains. The proportion of the population engaged in agriculture is high (average 56%), with some countries having over 80% of their population engaged in agriculture. Such heavy employment in agriculture means that the level of economic development in many places is low. It is clear that with the present rate of population growth a continuation of the slow agri-

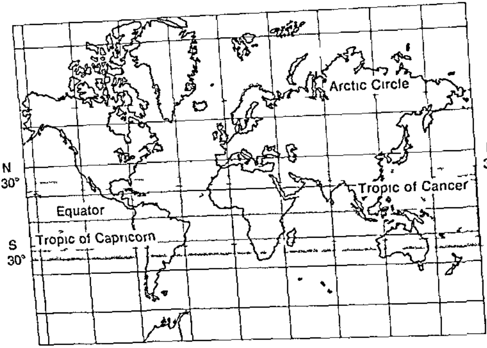


FIGURE 1 1
The warm climate region of the world is represented in this drawing by the shaded area

cultural progress of the past will neither buy the time needed for nations to stabilize their populations nor contribute to accelerated economic development

THE CURRENT STATE OF ANIMAL AGRICULTURE

The N S 30° region contains a substantial part of the world s livestock (Table 1 1) But in much of the region, animal agriculture has re ceived little attention in relation to either its present or its potential importance At present, the average milk yield and rate of growth of cattle in the lower elevations of the region are only 10–25% of what is acceptable in the northern latitudes Because of slow growth rates and high annual mortality, the numbers of animals available for meat supplies are also very low—one sixth to one third of the corresponding figures for the cooler latitudes The causes of these deficiencies are numerous, but feed supplies are of primary significance

The situation can be illustrated by considering a typical animal growth rate for the region in question Although few data are avail able on the growth rates of cattle outside the temperate zones, Figure 1 2 shows a reasonable approximation of the pattern of growth for

TABLE 1.1
Approximate numbers of the most important types of livestock and poultry found in the North-South 30° latitudes of the world and the proportion this region contains of the world total.

Types of animals	*Numbers*	*% of world total*
Cattle	592,055,000	55.1
Swine	201,258,000	34.2
Sheep	371,734,000	36.2
Goats	253,734,000	67.3
Buffaloes	96,435,000	79.8
Camels	10,142,000	86.2
Horses, mules, and asses	63,585,000	53.2
Poultry	1,300,000,000	26.7

Source. Data from FAO

cattle in a warm climate with a 7–8 month wet season and a 4–5 month dry season, in which the animals are dependent upon feed supplies from natural grasslands. Parturition generally coincides with the early part of the wet season, and the calf is automatically weaned at about 8 months of age or shortly after the dry season begins. The animal then experiences a period of weight loss, before the onset of the next favorable season (wet). Market size (400–450 kg body weight) is generally attained at 50–60 months of age or after about the fifth wet season. Since each animal requires 1–3 hectares of grazing land the first year after weaning, and 5–7 hectares in subsequent years, it takes a relatively large area of land and high inventory of animals to produce as few as 50 steers suitable for marketing each year. This makes for an extraction rate of less than 7% (ratio of animals sold to all the animals 8 months and older, × 100), which is very low compared to the 30–35% extraction rate considered satisfactory for much of the cooler latitudes.

The pattern for animal growth in Figure 1.2 by no means represents the poorest environment. The seasonal fluctuations in growth are more pronounced where the favorable periods last only 4–6 months, as in many parts of Africa and other tropical areas. Under these conditions the cattle must be either held for 7–10 years to attain market weight of 400 kg or sold at lighter weights.

In India the growth rate of cattle is often further retarded by the practice of allowing the calf to take only part of the dam's milk, the remainder going for human consumption. Such a calf weighs only 60–70 kg at weaning and is therefore not big enough to go it alone on

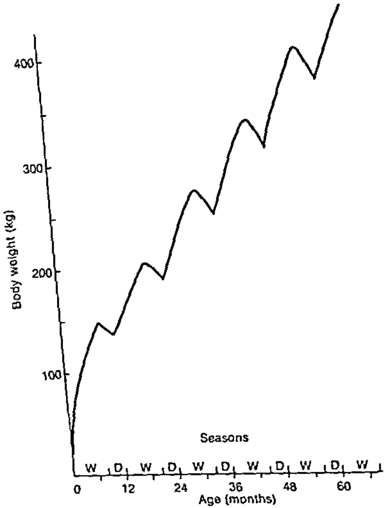


FIGURE 1.2
Typical growth curve for cattle on unimproved tropical grasslands in areas with 4-month dry season (From McDowell 1968)

roughages, especially when it is given only mature grasses or *pousa* (crushed dry rice or wheat straw) Its chances of survival to the next favorable feed season are markedly reduced If the calf survives, it will probably weigh only 120 kg at the end of the second wet season and approximately 270–320 kg at 6–7 years All indications are that when the milk yield of the cow is low, using part of the milk for human consumption and part for the calf is not economically feasible either for the production of stock or for the sale of milk In addition to large environmental influences created by the direct and indirect effects of climate, there is evidence that the genetic potential for milk yield and growth rate of most cattle native to India and other

areas is low. These limitations, coupled with traditional practices, such as milking with the calf present, creates a rather dismal future for commercial dairying.

Buffaloes are raised much like cattle in India and elsewhere. They are generally larger than cattle at maturity, but the age of first parturition is correspondingly delayed. Sheep, goats, and camels are largely restricted to the semi-arid areas, and consequently their turnover rate for marketable animals is as low as, or lower than, the rate for cattle. Only poultry and swine have benefited substantially from modern husbandry practices.

The following discussions provide additional illustrations of both the current practices and improvements being made by some in livestock production in the warm climates. As we think in terms of possible improvements we must keep in mind that the animals in this region are generally the product of two basic processes: unconscious selection by man for their ability to produce modest yields under limited resource conditions, and natural selection of survivors of poor feed supplies and constant attack by diseases and parasites.

SOME INHIBITORS FOR LIVESTOCK PRODUCTION

The basic principles for successful livestock production in the warm climates are similar to those for cool or temperate climates, namely, good systems of breeding, feeding, and management. However, due to certain factors operating in the warm climates, the approaches necessary for improvement may differ considerably.

In any region of the world a major problem associated with the development of livestock industries is the supply of feed. This problem is acute in much of the N-S 30° region, yet wide seasonal variations have an important influence on feed production in all latitudes. If livestock producers in New York State did not supplement the natural forage resources in the winter months, the mortality and morbidity losses among their animals would be higher, and returns from cattle or other species lower, than those current in the warmer climates.

Figure 1.3 illustrates the seasonal availability of feed supplies for grazing ruminants in three latitudes from unimproved grasslands, that is without the addition of such items as improved seed or fertilizer. The areas represented are central New York (temperate), southern Louisiana (subtropical) and the low elevations of northern Colombia (tropical). There are two distinct seasons in all three areas due,

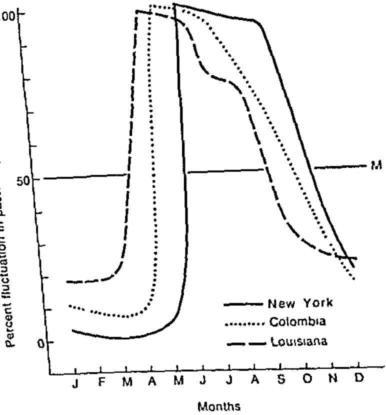


FIGURE 1 3
Seasonal fluctuations in quality and quantity of natural grasslands in three latitudes temperate (New York) subtropical (southern Louisiana), and tropical (lowlands of Colombia) The peak of each curve represents the period of highest quality and values for the other months are plotted as estimated deviations from the best period The horizontal line (M) portrays the approximate marginal point in animal maintenance requirements and weight gains (Adapted from McDowell 1968)

in the first two, to seasonal fluctuations in temperature and in the third to rainfall distribution These seasonal changes have a marked impact on feed resources as well as on other factors affecting livestock production In the temperate region, as represented by Binghamton, New York (latitude 43° North), the precipitation is distributed more or less uniformly throughout the year (Table 1 2), but the variation in temperature between the warm and cold months creates two distinct seasons for forage production Temperature changes create a nearly similar diversity of season in Louisiana In Colombia, the average precipitation is nearly the same as for Binghamton, but the irregularity, coupled with high rates of evaporation, brings about the two audible seasons—7–8 months wet and 4–5 months dry—which are important in maintaining uniform feed supplies from grazing

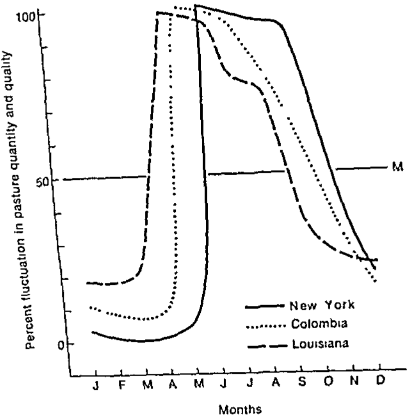
TABLE 1.2
Mean monthly dry bulb temperatures (°C) and precipitation (cm) for a representative area of the tropics, subtropics, and temperate zones.

	Tropics (Cartagena, Colombia: elev., 5m; lat. 10°28'N)		*Subtropics* (New Iberia, Louisiana: elev., 6m; lat. 30°N)		*Temperate* (Binghamton, New York: elev. 264m; lat. 42°5'N)	
Months	*Temp.*	*Prec.*	*Temp.*	*Prec.*	*Temp.*	*Prec.*
Jan.	27.2	0.0	13.3	13.4	−3.3	6.8
Feb.	27.2	0.0	14.4	11.4	−3.3	5.6
Mar.	27.8	0.2	15.6	14.7	1.7	7.4
Apr.	28.9	1.5	20.0	12.4	7.8	7.8
May	28.9	8.4	23.9	12.7	14.4	9.4
June	28.9	13.0	27.2	12.7	19.4	9.1
July	28.9	7.1	27.8	16.5	21.7	9.4
Aug.	28.9	12.7	27.8	13.2	20.5	8.9
Sept.	28.9	13.2	25.6	12.4	17.2	8.4
Oct.	28.3	22.3	20.5	7.1	10.6	7.4
Nov.	28.3	11.4	15.0	11.7	5.0	6.9
Dec.	27.8	1.0	13.3	14.0	−1.7	6.1
Annual	28.3	90.4	20.5	151.9	8.9	92.0

Source: McDowell, 1966

In Figure 1.3 the ordinate values are expressed as percentages of the highest quality and quantity of natural forages available during the year, with the other months expressed as deviations from the high period. As best as can be determined, the duration of the peak period is nearly the same in each of the three areas. The rapid decline in the summer months can be attributed largely to changes in the quality of the forages; consequently, the major differences among the three environments arise during the cooler, or drier, months, as the case may be. The horizontal line (M) in Figure 1.3 shows the approximate marginal point between the animal's needs for maintenance alone versus maintenance plus body weight gain. Comparison of the corresponding periods below the line indicates that the portion of the year during which natural feed supplies would be marginal to submarginal is nearly the same (7 months) in all three areas.

When there is high variability in feed supplies, marked fluctuations arise in the rate of weight gain of grazing animals (Figure 1.4). The rate for cattle more than 1 year of age may reach 0.6 kg or higher per day, but this normally lasts only 1 to 3 months. During the dry season in Colombia or the winter months in Louisiana losses in body weight may occur at a rate of 0.4 kg per day even though some graz-



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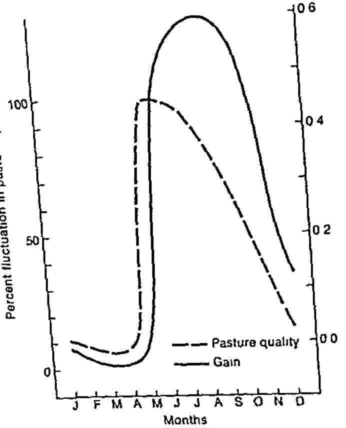

FIGURE 1 4
Illustration of seasonal changes in feed supplies and fluctuations in weight gain per day throughout the year for cattle on unimproved tropical pastures (From McDowell, 1966)

ing—albeit of poor quality—is available With losses of this magnitude, the net rate of daily gain for the year is between 0 2 and 0 3 kg per day The major part of the feed supplies thus goes just to satisfy maintenance requirements

Where the duration of the rainy season is only about 4 months, as it is in most of India, or 5–6 months, as in large areas of Africa, the decline in availability of feed due to irregular rainfall, coupled with land shortages and existing agricultural practices, makes the livestock feeding problem acute In a typical rural village of about 50 households in the central plains of India, the villagers cultivate approximately 165 hectares of tillable land and use 12 or more hectares as communal grazing lands The latter are ordinarily eroded, rough, and generally unsuited for cultivation under present agricultural practices (Nightingale, 1969) The villagers own 20 pairs of bullocks, which are used for field work, plus 80 additional cattle, which besides providing

replacement bullocks, produce dung for fuel and milk both for home use and for sale in a nearby town. The cattle are given the grass grown along the borders of the cultivated plots, and also weeds and grasses harvested from the fields while the crops are growing. In the dry season the animals subsist mainly on wheat or rice straw. The total feed energy needed by the animals for reasonably good performance far exceeds that available. There are no crops grown especially for feeding the cattle due to the need to grow food for human consumption and the insufficiency of the rainfall under existing methods of tillage and crop harvesting (Mellor, 1966).

The serious variations in feed supplies occurring in all latitudes indicate that providing for the continual needs of livestock is a common problem. There are, however, also inhibitors peculiar to warm climates, some of which relate to methods of agricultural production and others to the effects of climatic conditions on the characteristics of the forages available. Forages can be produced in abundance, particularly in warm, humid areas, but they are generally low in protein and digestible energy for reasonable levels of animal performance. In contrast, the grasses of the 40–50° latitudes have considerably higher nutritive value, except at the most advanced stages of maturity. As they advance beyond a few weeks' growth, most tropical forages have a characteristically high lignin content, which influences both digestibility and the amount the animals will eat. The tropical grasses also tend to be lower in soluble carbohydrates than the temperate zone forages. As a consequence, the sugar–protein ratio in tropical grasses is usually at a level below that for producing enough lactic acid to make acceptable silage. Lack of suitable legumes is another serious handicap in much of the region.

Consistently low animal nutrition leads to high susceptibility to disease and parasites. Diseases specific to certain parts of the region such as rinderpest and East Coast fever, along with many other diseases and parasites, cause exceedingly high losses in animal productivity. Even so, the animal health problems that are, in general, worldwide, such as mastitis, tuberculosis, brucellosis, nutritional disorders, and diarrhea, cause the greatest losses by both death and morbidity in the N–S 30° latitudes. Accordingly, the problems associated with animal health exceed those of temperate regions.

The problems of poor nutrition and disease are often worsened by an excess of animals to be supported by the environment. This is brought about largely because individual farmers and community or tribal groups do not regulate their stock numbers according to available feed supplies. Keeping animals is, of course, a natural hedge against total loss from epidemics and other natural disasters.

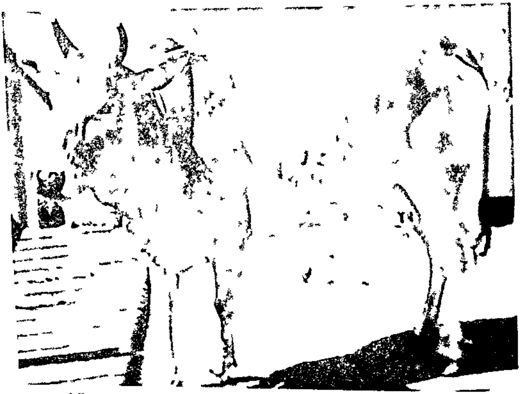

FIGURE 1.5
A Deshi cow native to northeastern India and Bangladesh Its mature weight is 200 kg and it has average lactation milk yield of 330 kg It is rather temperamental and must have calf present at milking time

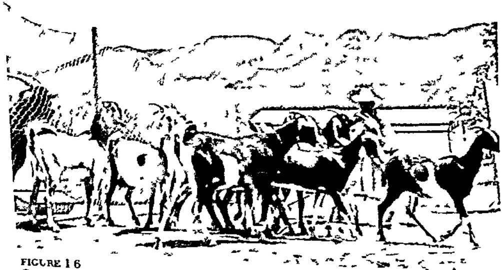

FIGURE 1 6
Group of native goats found in the dry region of north central Venezuela Each weighs 20–25 kg at maturity and yields 10–40 kg of milk per lactation The owners slaughter them and display carcasses by the roadway to attract buyers Hides are tanned and made into handbags and other leather goods

Much of the time the prevailing temperature and humidity in the warm climate region imposes stresses on animals. When this transpires, the animals must expend extra energy if they are to maintain their thermal balance. This results in a low input-output efficiency of feed energy for productive processes as compared to that of cooler climates (McDowell, 1968).

The fact that programs for genetic improvement in the warm climates are few constitutes yet another inhibitor to successful livestock enterprises. There are very few organized systems of record keeping including more than single herds, and consequently there is little emphasis on selective breeding through progeny test. In general, the genetic potential of the animals indigenous to the warm climates is so low in many places that commercial animal production cannot be a paying business. Many of the stocks are extremely small (Figures 1.5 and 1.6). This characteristic does afford distinct advantages for the animal's survival when food is scarce, but it is a serious disadvantage for greatest efficiency in growth or milk yield with reasonably good levels of feeding.

Incentives to increase production are often low for the majority of the livestock owners because of inadequate marketing organizations including processing and storage facilities for providing reliable supplies of products to consumers and feed to producers. Poor transportation is another serious deterrent to producer incentive. For example, after cattle have been trailed a distance of 400–600 km, there may be little profit from their sale because of the weight shrinkage (Figure 1.7). Transportation is also a problem in handling feed sup-

FIGURE 1.7
Group of cattle arriving for market in Ibadan, Nigeria after being trailed from near Kano 600 km to the north. (Courtesy J. K. Loosli, Cornell University).

or tillage and irrigation are carried out with animal power (Figures 1 10 and 1 11)

The system of land tenure can be a further inhibitor to potentially successful livestock enterprises since many of the owners reside away from the farms They have other interests and income, hence they give little attention or guidance to those working with the stock If the operation is on an owner tenant share basis, the owner generally forces the tenant to bear the major burdens of the fluctuations in livestock output resulting from drought or a serious outbreak of disease

A major inhibitor to efficient livestock production may often be the traditional cultural practices of the particular locality For instance, in the central plains area of India it would be wise for farmers to dispense with at least half of the cattle and to use all of their feed resources for the remainder Although this thinning practice has been advocated, it cannot as yet be implemented because of the existing stigma against slaughtering cattle But perhaps of even greater significance to the problem is the lack of cheap sources of household fuel other than animal dung Villagers would be very reluctant to relinquish not only their sole supply of fuel but also the cash returns realized from the sale of cow dung cakes to urban areas In some localities, over 60% of the annual cash income of rural villages is from the sale of dung (Nightingale, 1969)

Other problems are those of insufficient capital for implementing innovations in husbandry, dearth of appropriate technology, poor educational background of the intended users of technology, and inadequate means of informing farmers about worthwhile changes

The foregoing is by no means a full enumeration of the problems that may be encountered to one degree or another in the N-S 30° region Collectively, they create quite a dismal picture for potential improvement in livestock production, but we can take consolation in the fact that farmers in the cooler regions have been confronted with problems of equal magnitude, yet have managed to develop efficient and productive enterprises The same holds true for some producers in the N-S 30° latitudes Certainly the region already contains some of the most efficient livestock enterprises to be found anywhere

Over the past 30 years Israel has developed a highly efficient livestock industry Its production of 78 2 tons of beef and veal per 1000 animals exceeds that of the U S (FAO, 1969), and the milk yield per cow per lactation leads the world In the area around Maracaibo, Venezuela, profitable dairy enterprises have been developed utilizing the native Criollo type cattle and a good pasture program for the major feed supplies (Figure 1 12) In the hill region of Puerto Rico, high grade or pure Holstein cattle have given good performance from

FIGURE 1.12
Group of lactating Criollo cows on well managed pastures near Maracaibo, Venezuela.

FIGURE 1.13
Holsteins and Holstein-native crosses on an excellent pasture of Pangola grass in the hill region of central Puerto Rico (Courtesy of R. Caro-Costas Puerto Rico Agric. Exp. Sta.).

plies as a large amount of labor is required for harvesting and transporting the feed to the animals (Figure 1 8)

Where the principal objective of the farm enterprise is the production of crops the methods of production are frequently so time consuming that neither the farmer nor his family has the time or the energy for developing feed supplies for livestock This applies whether all the work is done by hand as illustrated in Figure 1 9

FIGURE 1 8
Donkeys are frequently used for the transport of green cut forages for feeding cattle and buffaloes in Egypt In winter it is Berseem clover and in summer it is fodder stripped from growing maize

FIGURE 1 9
Small farms on relatively steep slopes open overgrown lands by cutting and some by mining Due to the presence of stumps fallen trees rock outcroppings and the slope of the land, all planting and harvesting must be carried on by hand.

FIGURE 1.10
Preparation of land with wooden plow and team of oxen by two to four plowings consumes a lot of precious time where the favorable growing season is restricted to a few months by low rainfall. (Courtesy H. C. Pant).

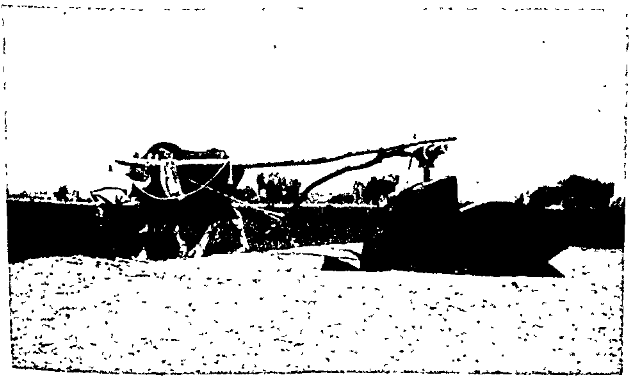

FIGURE 1.11
Buffaloes are considered more adaptable than cattle for monotonous tasks such as operating a water lift for irrigation. This method of water distribution is so slow that much of it evaporates before reaching the crops.

grazing solely on highly fertilized, well managed pastures of improved species of grasses (Figure 1 13)

The Kaira District Cooperative Milk Producers Union in the area around Anand, India represents an excellent example of how small farmers can be helped to overcome many of the inhibitors to profitable livestock production in that locality These are all examples of what can be done, but unfortunately, for reasons both known and unknown, the vast majority of livestock producers have experienced little or no change for the better

THE NEED FOR LIVESTOCK IMPROVEMENT

Since livestock provide for three products important to human welfare and economic development, namely, food, fibers, and finance, the improvement of livestock production seems to be a worthy objective.

There is a great need for better food supplies At present the daily per capita consumption of animal protein in the warm climates averages no more than 18 grams, which is 30% lower than the world average and 60% less than for countries in the 40–50° North latitudes North Americans consume an average of about 1 liter of milk, in various forms, and 1 egg per day In southeast Asian countries, with only 220 kg of grain per person per year, and very little of that going for feeding livestock, the average consumption is only about 1 liter of milk every 2 weeks and 1 egg every 10 days Many of the people whose diets are most in need of improvement have a notoriously poor record of acceptance of new foods, but in these areas livestock are already widely distributed and their products accepted Thus livestock production is particularly important here

Another major reason for improving livestock production in the warm climates is that the population is highly dependent on livestock for products and services other than food These include power for agriculture and other applications, as well as materials such as fibers and leather Animals also play a significant role in recreation and in cultural rituals

The details of livestock production differ widely from country to country in the warm climates The meat yield of cattle varies from 12 6 tons per 1000 animals in Venezuela to 0 4 tons in Thailand, and even lower in other countries, compared to over 40 tons in the U S For milk, leaving aside countries for which no data are reported (because milk is not traditionally consumed after weaning), production varies from a high annual level of 37 tons per 1000 persons in Israel

to 0.2 tons in Indonesia. These wide variations in production of meat and milk indicate an important reason why so many countries are deficient in animal protein for human food, but they also indicate the possibility of overcoming these deficiencies. Although lying outside the warm climate region, Japan's efforts to fit dairy production into its pattern of agricultural production (Yang, 1962) represent an example of how a country, even with the most intensive cropping system in the world, can add to its animal protein supply through dairy production, if it has the desire to do so.

When the annual extraction rate of animals kept for meat production is less than 15% per 100 animals maintained, the contribution to agricultural production, in proportion to the enormous amount of natural resources (including land and labor) invested in these animals, is very low. Latin America, for example, has twice as many cattle as the U.S. but produces less than half as much beef. The ratio of productivity is 1:4, meaning Latin America feeds four times as many cattle as the U.S. to produce 1000 kg of beef. This ratio must be narrowed to expand food supplies as well as to improve farm income.

Expansion of animal products could also help to diversify exports. Good quality meat, for which world demand is vigorous, could be an important export for warm climate countries, especially in view of the difficulties of competing with other countries in manufactured goods.

Without breakthroughs already taking place in food grain production, it is logical for livestock production to serve as a complementary rather than competitive enterprise. Cattle and other livestock, by utilizing surplus grains and residual crop materials, effectively act as a market stabilizer for grain and provide returns from products that would otherwise go unused. With crop rotation necessary for best use of the improved varieties of cereal grains, livestock can also serve to provide a return from grasses or other crops used in the rotation scheme.

In many places, mostly around urban centers, the by-products from the processing of foods for human consumption are rarely utilized as fully as possible. Thus even though land costs in such areas may be high, well operated livestock enterprises could turn a profit.

It has been demonstrated that small farms with livestock generally fare better economically over a period of years than small farms relying solely on crop production (Deans, 1969). This is because crop farmers may suffer complete loss from a drought, whereas farmers with livestock have some reserves for their own food needs or can generate capital for crop renewal through the sale of livestock without incurring heavy debts.

Seemingly, the case for more efficient livestock production in the warm climates is a good one in spite of the many potential inhibitors But if the producers of livestock and poultry are to meet the challenges, they must be prepared to make changes If they are to breed and manage livestock in a fashion that will produce efficiently and return a reasonable profit, they must increase their understanding of animal breeding, physiology of reproduction and nutrition, and the complex problems of feeding, management, and marketing They must become more cost-return oriented and more aggressive in cooperative efforts among themselves in order to better their own welfare and to enhance their reputation with consumers through having uniformity of supply and good quality products It is against this background that we undertake the study of why livestock production is low in the warm climates and how we might bring about adjustments

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2

The Physical Environment

Domestic livestock are essentially our factories or chemical plants for conversion of the potential energy of feed into forms having utility for man As with all factories, it is economically desirable for the ratio of useful output to input to be as high as possible Many of the components of the surroundings imposed by both nature and man influence the input output ratio Collectively these are referred to as the physical environment For the near optimum ratio in cattle, sheep, or buffaloes, we would like a climatic environment having an air temperature of 13–18°C, a relative humidity of 60–70%, a wind velocity of 5–8 kmh (kilometers per hour), and a medium level of solar radiation, similar to that occurring in subtropical latitudes in the spring and fall seasons There should also be a fertile soil with adequate and evenly distributed rainfall to produce crops of high quality in plentiful supply And finally, the environment should be free from diseases and parasites Of course this represents a utopia, which hardly exists anywhere in the world as a natural environment

The prevailing temperature, relative humidity, and levels of solar radiation of the N S 30° latitudes are generally above our ideal or comfort range for optimum efficiency of livestock performance Thus

livestock operators must consider ways of modifying the impact of the environment on the performance of their animals. Some understanding of how the various elements of the physical environment influence the animals both directly and through their interactions, is extremely important. The last two decades have seen a rapid development of interest in understanding climate-plant-animal relationships.

Improvements in the precision of estimating the environment in relation to agricultural and animal production stemmed largely from the development of the field of biometeorology, the study of the direct and indirect interrelationships between the geophysical and geochemical environment of the atmosphere and living organisms, plant and animal. Although much remains to be learned in this field, the principles already established could aid livestock producers in their decision making.

Before proceeding, a few key terms should be defined. "Weather" comprises the group of day-to-day, changing meteorological conditions, such as temperature, precipitation, and air movement; "climate" comprises the average weather conditions of a region, or in other words, the average values of the total group of meteorological phenomena over several years. "Macroclimate" refers to the conditions prevailing in a region or country; "microclimate" refers to the conditions the animal is exposed to directly at any given time.

Since man's physiological processes are very sensitive to changes in temperature and air movement, and to a somewhat lesser degree to the humidity of the air and the solar radiation of the surrounding environment (microclimate), man has looked primarily at the direct action of these elements on the performance of his animals. The problems of livestock management would be simplified if it were necessary to consider only the direct effects of the microclimate on the animal. But, in most situations, this would be an oversimplification as the indirect effects, operating through the feed supplies or other factors created by the macroclimatic environment, often confound the solutions and many times far overshadow the direct effects of the climatic elements. As man attempts to modify environmental conditions to attain satisfactory animal functioning, he must consider both the micro- and macro-climatic influences.

THE ENVIRONMENTAL VARIABLES

In Figure 2.1 the elements of the animal's usual physical environment are portrayed as spokes of a wheel. In this illustration, man serves as

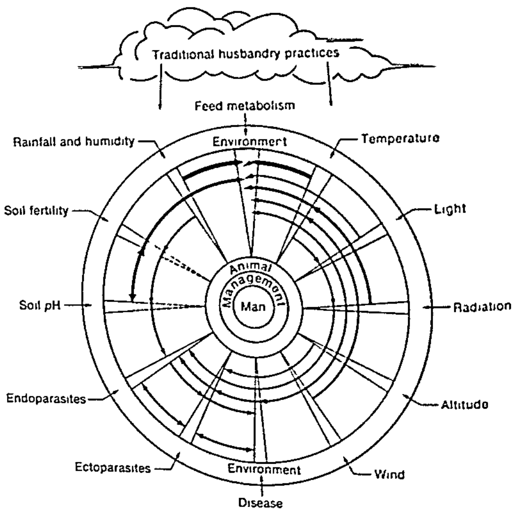


FIGURE 2 1
Elements of the physical environment that directly (direct arrows) or indirectly through their interactions (concentric arrows) influence the performance of the animal or the usual management regime employed (Width of arrows indicates the relative degree of influence) Coupled with the elements of the physical environment are the cultural or traditional attitudes of societies which must also be considered in bringing about structural changes (From McDowell 1967) Fig 1 p 279 *Ground Level Climatology* Pub No 86 Copyright 1967 by the American Association for the Advancement of Science

the axle, his animals the hub, and his management practices the lubricant that keeps the wheel in motion The running surface of the wheel represents the total environment, which is held in shape by the spokes, typifying the influences of various elements The concentric lines show the important interactions among these elements If the influence of an element reaches the extreme, a spoke will be broken and the delicate balance between the environment and the animal upset (Bonsma, 1958)

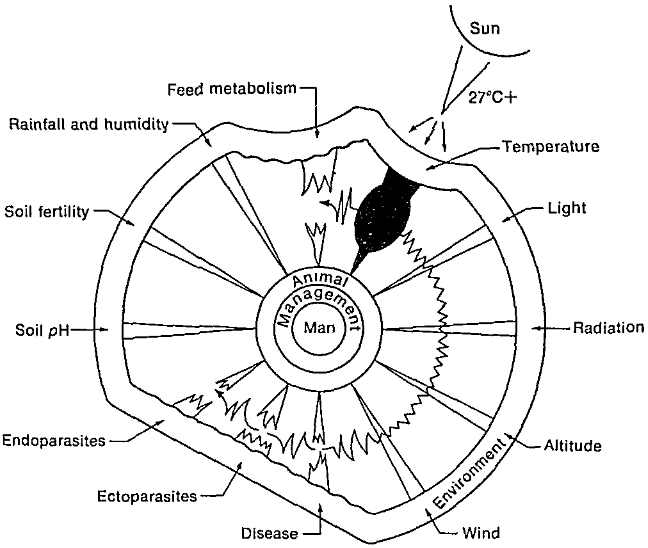


FIGURE 2.2
The probable direct and indirect influences (interaction effects) that 27°C or above air temperature will have on livestock in the N-S 30° latitudes. (From McDowell, 1968).

If the animal is subjected to temperature conditions 8–10°C higher than its optimum range of 13–18°C, the wheel reflects this by a depression, as shown in the top portion of Figure 2.2. Such circumstances would cause the animal some degree of discomfort and stimulate certain reactive physiological processes, bringing about changes in general behavior, including decreased food intake, and some reduction in efficiency of the energy input-output ratio. But in spite of these direct effects, the wheel would continue to roll although less effectively than before due to the indentation made at the point of temperature. Under the conditions portrayed, however, the major impact of the change in temperature would not be through direct action but rather through indirect pathways. If the high temperature conditions were continuous, as they are in much of the N-S 30° latitudes, the indirect effects on the animal through inadequate or poor quality feed, disease, and parasitism would cause the wheel to collapse, as

illustrated in Figure 2 2 When several spokes of the wheel collapse, the environment is such that the animal becomes submarginal in both efficiency and total productivity

A further complication of keeping the environmental wheel in balance is that traditional animal husbandry practices, such as fencing animals to keep them from reaching shade during the hottest part of the day or placing them in an enclosure to prevent grazing during the cooler evening hours, frequently prevent appropriate judgment of the direct effects of climatic conditions on animal comfort and performance

It is readily apparent from Figures 2 1 and 2 2 that an awareness of the average expected climatic conditions, their seasonal variations, and the extent and duration of extremes can be valuable in determining (1) the general feasibility of livestock production in an area, (2) the practices most suitable for feed production, (3) the probable needs for animal housing, and (4) the best general scheme for animal management

The extent to which meteorological data can be helpful depends a great deal on the intensity of the livestock enterprise If an intensive broiler production plant is planned, information on the prevailing temperature and humidity conditions, along with the extent and duration of extremes in these elements, would serve to determine the most suitable structure for housing the birds If temperature conditions during part of the year are likely to reduce the efficiency of feed utilization, the operator's knowledge of prevailing climatic patterns could help him decide whether to provide air cooling or to curtail operations during the season of greatest stress On the contrary, the man who keeps a few poultry running about the household would not ordinarily be concerned over seasonal fluctuations in the weather

If a dairy enterprise has an annual average milk yield per cow of 6000 kg or higher, a period when the mean daily temperature reaches 24°C or higher for 20 days or more in succession or in near sequence would cause losses in production, of economic significance both of an intermediate and of a carryover nature, unless some adjustments were made in management practices But the direct effects of a limited stress period would go unrecognized in a herd with an annual milk yield per cow of 4500 kg or less or in a herd kept for beef production

As later discussions will show, climatic elements other than temperature importantly influence the decisions of livestock producers

Seasonal changes have economic significance for intensive livestock enterprises in almost all areas of the world But their significance is particularly great in the lower elevations (<1000m) of the N-S 30° latitudes, where they influence such important decisions of

livestock production as choice of enterprise, selection of breeds, and management of feed supplies. Since there are areas, even in these lower elevations, where the duration of the extremes of climate does not create serious stress conditions for most domestic livestock, we shall restrict our discussion to the areas where the mean monthly temperature exceeds 24°C for 5 months or more. Such a period of high temperatures can be considered severe enough to create special problems for livestock handling. Areas that fall into this category, whether they be high or low in humidity, will introduce limiting agents for animals in the form of poor nutrition, interference with the desired level of reproductive efficiency and increased problems of disease and parasitism.

THE CLIMATIC ELEMENTS

In discussing the restrictive forces of climate in relation to animal production, most writers have used very broad classifications, for example, hot, humid or hot, dry. These are helpful to some extent but they are too broad for use with any degree of satisfaction in determining problems of animal husbandry. The current discussion of climatology will be oriented specifically toward climate in relation to the performance of farm livestock and demonstrate that some knowledge of expected occurrences of temperature, humidity, solar radiation, rainfall distribution and air movement is useful in determining the best means for maintaining the highest efficiency of performance by livestock. A text on climatology, such as Critchfield (1966) will serve to explain the nature of climate and some of the causes for the patterns that prevail in the warm climate regions. The features of equipment for measuring the climatic elements and recommendations on evaluation of data collected at a location are described in Nat'l. Acad. Sci. (1971).

Air Temperature

Importance

Air temperature is probably the most important single bioclimatic factor in the animal's physical environment. It has no rigorous definition as it is a relative term implying a degree of molecular activity, or heat of a substance. For practical purposes, the gross tem-

perature regime of any large area is determined by the amount of solar heat that falls upon it from one season to another The amount of solar heat depends upon the angle of the sun and the characteristics of the atmosphere Impurities in the air, such as dust, smoke, and high water vapor content, reduce the heat energy reaching the earth's surface Clouds also absorb solar energy, making the air temperature of the warm, humid tropics lower than that of hot, dry regions

The temperature of the ambient or surrounding air about an animal's body is extremely important to its comfort and general functioning of physiological processes Heat normally passes by conduction from the warm skin (about 33°C) of most species of livestock to the cooler air around it But as air temperature rises above the comfort range (13–18°C), the heat loss diminishes and if air temperature exceeds skin temperature, heat will flow in a reverse direction This can become a serious problem in hot, dry areas When air temperatures are low (<5°C), heat flow from the animal's body will be accelerated to the point of discomfort and lowered efficiency of performance (See also Chapter 3)

Besides heat from the air, the animal may be heated or cooled by the temperature of objects in its surroundings The most important source is heat from the ground Solar radiation heats dry soil rapidly, thus by mid afternoon an animal grazing on semi arid and arid areas may be exposed to a ground surface temperature >40°C This level of temperature causes the ventral body surface to take up a significant amount of heat However, the soil of hot, dry areas cools rapidly after sunset which gives the animal an opportunity to lose any stored body heat rapidly by conduction to the cooled ground Frequently the ground surface temperature declines below 5°C which adds stress to the animal by causing excessive heat loss from its body Ground surfaces well covered with green vegetation or moist soils heat more slowly, therefore ground temperatures are not generally an important source of heat gain for animals in hot, humid areas

The speed, direction and sources of wind have important bearings on the prevailing temperature Winds coming from oceans are more equitable and moist than those blowing across large land masses that are subject to rapid heating or cooling from solar radiation If an animal is grazing in a field where the temperature of still air is 25°C, it will not experience discomfort, but if, by mid afternoon, wind is coming from passing over dry land that is 40 C or higher, the animal's heat load will be markedly increased

The prevailing temperature pattern is also influenced by altitude Air temperature tends to diminish at a rate of 0 65°C/100 m increase in elevation This means that, in general, if the altitude exceeds

1000 m, ambient temperature conditions will not create stress on animals.

The prevailing temperature conditions have a very pronounced indirect influence on livestock through feed supplies and animal health problems. These relationships are discussed in Chapters 6, 7, 13 and 14.

Measurement

To measure the temperature of a body, an arbitrary scale of reference is employed. The two most common scales are the Fahrenheit and the Centigrade, or Celsius, scales. The most widely used measures of air temperature are the maximum and minimum temperatures. The average of these provides an estimate of the mean daily temperature. These three temperatures are useful for evaluating the thermal environment of a location in several respects. If data are accumulated over several years, the averages of each can be used to characterize expected conditions of temperature for various periods or seasonal trends.

It is possible for two locations to have nearly identical mean daily temperatures yet differ enough in their environments to require quite different management practices for livestock. For this reason, the maximum and minimum temperatures ought also to be examined for determination of the extremes of each and the range of daily variations. In an area where the humidity is high the difference between the daily maximum and minimum temperatures may be 8°C or less. If the minimum is near 24°C, the animal will likely be under some degree of thermal stress for almost the entire 24-hour period. Whereas, in a hot, dry climate the difference between the maximum temperatures may be 22°C or greater. Such a large difference means that night temperatures are within the comfort range for livestock. A cool night allows the animal to restore its thermal balance before encountering further stress the following day. Therefore, the best management systems for the two areas would be quite different.

A more precise estimate of the duration of stress, but one requiring more frequent observations of temperatures, is the percentage of the 24-hour period when the temperature exceeds 27°C. For example, the mean monthly air temperatures for Shreveport, Louisiana during May, June, July and August are approximately 23, 28, 28 and 29°C, respectively; but the corresponding percentages of time when the air temperature is expected to exceed 27°C are 26, 38, 60, and 62%. This shows a marked contrast in severity between June and July. At

Brownsville, Texas, the mean monthly air temperatures for May–August are 26, 28, 29 and 29°C, respectively, the expected percentages above 27°C by months are 44, 65, 72, and 70% The monthly means for Shreveport and Brownsville are similar from June to August, but difference between the two locations in frequency of occurrence of temperatures >27°C ranges up to 27%

Air temperature data for much of the N–S 30° latitudes are presently insufficient to characterize temperature patterns Collection of such data is well worth the effort for developing guidelines for livestock management It is not possible to establish mean daily averages that would serve for a day-by-day prediction or even for weeks beyond 50% reliability but with 5 years of data such values fall within a workable range (±3°C)

Atmospheric Humidity

Importance

The animal's physiology As mean daily temperatures fall outside the 13–18°C range, other climatic variables assume greater significance in the homeostasis of the animal The water vapor content or humidity of the air offsets importantly the animal's rate of heat loss The rate of cooling by evaporation from the skin and the respiratory tract depends largely upon the humidity of the air (See Chapter 3 for a description of the evaporation process) If the humidity is low, as it is in hot, dry areas, evaporation takes place rapidly—sometimes too rapidly, leading to skin irritation and general dehydration On the other hand, if the humidity is high, as occurs in warm, humid areas, evaporation takes place slowly, restricting heat loss and thereby endangering the animal's thermal balance Although problems of excessive water loss are often encountered in hot, dry climates, problems of heat retention in hot, humid climates are more acute

The importance of vapor pressure or water content of the ambient air in estimating the rate of heat loss by evaporation from the respiratory tract and skin is illustrated as follows

$$\text{Respiratory evaporation } H_r = 00057\ V\ (P_b - P_a)$$

where H_r = rate of heat lost from respiratory tract in kcal/hr, V = respiratory volume in liters per hour, P_a = vapor pressure of air in mm Hg, and P_b = saturation vapor pressure at body temperature in mm Hg

If the air temperature is 29°C and the vapor pressure is 22 mm Hg

(60% relative humidity) and a cow expires 130 l of air per minute, she loses about 2.07 kcal/m² of body surface per hour. If the vapor pressure increases to 29 mm Hg (90% relative humidity), with respiratory volume and air temperature unchanged, the rate of heat loss is reduced about 25%.

$$\text{Skin surface evaporation } H_{es} = \frac{K_{es}\,(P_c - P_a)}{r_a + r_c}$$

where H_{es} = heat loss from body surface (kcal/m²), K_{es} = constant depending on units used (5 for kcal/m² body surface per hour), P_c = vapor pressure of skin surface in mm Hg, P_a = vapor pressure of ambient air in mm Hg, r_a = resistance of ambient air (wind velocity), and r_c = resistance of hair coat.

Disease. Humidity also poses problems to the livestock industry by creating conditions conducive to disease, lowering feed quality, and accentuating mineral deficiencies in the soil and forages. High humidity, in particular, provides suitable environments for (1) free living disease organisms, (2) insects and other vectors of infective agents, (3) potential reservoir hosts and (4) maintaining suitable conditions on the skin for growth of bacteria, fungi, and ecto-parasites. This is very important in livestock production because where the incidence or severity of disease constitutes a major economic barrier, other modes of climatic action may take second place. Even poor nutritional conditions and the direct effects of the climate upon the animal may be of minor concern when the economic effects of diseases are marked.

Feed Supplies. When the temperature and humidity are high, many species of forage plants undergo rapid growth, but with an accompanying increase in lignin content and reduction in both nitrogenous and carbohydrate content. The animal then needs to eat more to satisfy its nutritional requirements but instead eats less because the forages are less palatable. Excess humidity also tends to lower the dry matter content of the forage. For example, Napier grass grown under high humidity conditions may have a dry matter content of less than 15% with an energy content of approximately 0.04 Mcal/kg, or 9.0 kg of total digestible nutrients (TDN) per 100 kg of green material.

Housing. Humidity also affects animal comfort in confined housing. Because the animals give off water vapor, humidity is increased when they are housed in close proximity without sufficient rate of air exchange to expel the excess water vapor.

At high temperatures, both high and low humidities have marked effects on the well-being of livestock In warm, humid areas, where air temperatures are 21°C or above, humidity becomes a problem for livestock production when the relative humidity is 60% and above, or the vapor pressure is above 20 mm Hg In hot, dry areas where air temperatures may exceed 32°C and the wind velocity is relatively high, low humidity levels (<20% relative humidity or 10 mm Hg vapor pressure) become hazardous

The possibility of indexing the degree of tropicality with a combined index of temperature and humidity will be discussed under climatic classifications The impact of extremes of humidity on normal physiological functions and performance will be taken up later with the physiology of heat regulation

Measurement

It is customary to describe atmospheric humidity in terms of relative humidity (the ratio between the amount of water actually present in the air and the amount it would hold if saturated at the same temperature) But the skin and lungs of homeotherms maintain a more constant level of temperature, and evaporation from them takes place into a contact layer of air at the same temperature So relative humidity gives little indication of the ability of the atmosphere to accept water vapor from the skin and lungs Vapor pressure (the concentration of water vapor in the air expressed as the fraction of the total barometric pressure contributed by the gaseous water molecules) is a better measure of humidity in relation to animal comfort because it provides a more precise estimate of the water content of the atmosphere Since the amount of water vapor the air can hold fluctuates with its temperature, the relative humidity corresponding to a given vapor pressure varies with the temperature For instance, a vapor pressure of 20 mm Hg corresponds to a relative humidity of 100% at 22°C, 50% at 34°C, but only 30% at 43°C Relative humidity can be measured directly with a hygrothermograph or indirectly as wet bulb or dew point temperatures Vapor pressure can be determined from meteorological tables using air temperature and wet bulb, dew point, or relative humidity Dew point is another term frequently employed to describe the water content of air, it is the temperature at which the air would be saturated by the amount of water present in it.

The average daily maximum relative humidity occurs in the early morning hours and the minimum in the early afternoon, however, the vapor pressure and dew point temperature may be nearly constant

throughout the day. Thus, as is often the case, estimates of daily relative humidity based on early morning hours (7 A.M.) overaccentuate the humidity conditions the animals will experience during the hotter part of the day.

Further details on the relative merits of the various measures of water content in the atmosphere and techniques of measurement may be obtained from one or more of the references at the end of the chapter.

Radiant Energy

Importance

Probably the most economical way of assisting an animal to maintain its heat balance in a hot climate is to provide some control over the incoming thermal radiation. Radiation from the sun, sky, and surroundings often adds to the animal's heat load. However, it can ordinarily be reduced substantially with shades or shelters that cut off most of the direct solar energy and lower the reflected radiation.

An animal grazing in an open field is exposed to (1) direct solar radiation (visible and short infrared waves) from the sun, part of which is reflected according to color and other properties of the coat and the remainder absorbed as heat, (2) solar radiation reflected from clouds and other particles in the sky, part of which may be reflected by the hair coat, and (3) solar radiation reflected from the ground, other surrounding objects, and the horizon. Of the total radiant heat that an animal is subjected to out in the sun, approximately 50% comes from the first two sources and the remainder from the third. This, however, varies with the humidity. Figure 2.3 shows the sources and the approximate proportions in kcal/m^{2}h received by an animal exposed to the sun on a typical August day near El Centro, California.

Solar radiation is the radiant energy that comes directly from the sun which is received at the earth's surface. The constituent wavelengths range from 0.1μ (equal to 10^{-4} cm) in the ultraviolet to 100μ in the infrared, but the energy is not uniformly distributed over the whole range. The ultraviolet contributes only about 1%; the visible range contributes 40–45%; and the infrared range contributes the remaining 50–60%.

Terrain is an important factor in determining the amount of radiant energy in any environment. In general the level of radiant energy is negatively correlated with the humidity, but radiation level has a high positive correlation with maximum temperature. A white

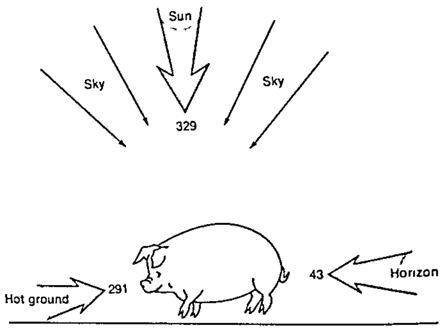


FIGURE 2 3
The radiation received in kcal/m²h by an animal out in the sun on a typical August day near El Centro California (Adapted from National Acad Sci Publ, 1971)

painted surface reflects a high proportion of visible radiation but very little long infrared Polished aluminum, on the other hand, reflects high proportions of both (85% of the shortwaves and 92% of the longwaves, or thermal radiation) and hence takes up very little heat (Table 2 1) In contrast, black matte reflects very small amounts of either the shortwaves or longwaves, it absorbs most of the heat resulting in a high level of emissivity From these comparisons it is readily evident that selection of roofing material can be important (See also the section on shelters in Chapter 14)

The longer the wavelength, the lower is the probability that the waves will encounter continuous materials of sufficient size to arrest their penetration, this lowers the probability of reflection and increases the chance for absorption It is not surprising, therefore, that the skin of an animal absorbs most of the long infrared radiation but may reflect considerable proportions of short infrared and even greater proportions of the visible incidence A white hair coat or feathers can reflect most of the incidence of visible radiation (wavelength 0 3–0 8μ), less of the short infrared (0 8–2 5μ), but practically none of the long infrared

The energy content of the radiation absorbed by the animal's

TABLE 2.1
Reflectivities and emissivities (in percent) of some typical surfaces.

Surface	Reflectivity: To solar[a] radiation	Reflectivity: To thermal[b] radiation	Emissivity to thermal radiation
Aluminum, polished	85	92	8
White lead paint	75	5	95
Light green paint	50	5	95
Aluminum paint	45	45	55
Wood, pine	40	5	95
Brick, various colors	23–48	5	95
Gray paint	25	5	95
Black matte	3	5	95

Source: Adapted from Lee, 1953
[a]Primarily shortwaves.
[b]Longwaves.

body is changed into heat, raising the temperature of the animal according to the ordinary rules of conduction and convection.

The assessment of the total radiation to which the animal is exposed and the amount it absorbs or reflects becomes a very complex process. Measurement of the sources of radiation is in itself complex and still does not describe completely the heat load imposed on the animal. The animal's posture, shape, size, frequency of movement, and length of hair coat, as well as the angle of the sun and other factors make satisfactory measurement of the incidence on the whole animal body little more than a gross estimate. When the sun is overhead in a clear sky, the intensity of radiation may be high, but the extent of the surface presented to it by an animal may be relatively small in proportion to its total body surface. This varies among species. At noon, man will have little more than the top of his head exposed to the full direct radiation, whereas a sheep will have the full length of its body exposed. Because of posture differences, man will have the greatest surface exposed between 8 and 10 A.M. and 4 to 6 P.M.; sheep will have their greatest surface exposed from 10 A.M. until 12 P.M. solar time. As the angle of the sun decreases, the intensity decreases; thus a man is likely to receive much less direct radiation during a day than a sheep or cow. The calculated heat load of 663 kcal/m^{2}h for a pig under a noon-day sun (Figure 2.3) does not mean the animal's whole body takes up this amount of heat. The actual amount is considerably less because of the configuration of surface, reflection, and reradiation. No one knows what the true rate of exchange is and researchers

are reluctant to spend the time required to find out because any estimate derived would apply to only a single set of micro conditions

Measurement

One means that may be used to acquire approximate estimates of the total radiation exchange—other than direct solar—of an animal exposed to a particular environment is the black globe thermometer, which is a sphere fitted with a thermometer, thermistor, or thermocouple for recording temperature The black globe temperature is normally 6°C above the atmospheric temperature, so it has been used in lieu of the atmospheric temperature to estimate the rate of heat gain by the animal in a particular environment

Since much more research is needed to properly assay the amount of radiant energy in particular areas and the amount of heat the animal takes on, only general rules can be applied at this time From 6 to 12 months of the year in the lower elevations of the N–S 30° latitudes, the intensity of direct and reflected radiation is such that for 5–10 hours per day the animal may receive significant amounts of heat The radiant heat load is greatest in the afternoon, when the ground radiation and air temperature are high But the duration of the stress period from radiant energy may extend beyond the daylight hours, particularly if the animals are housed under a shelter that has a high emissivity of thermal radiation (See Chapter 14 for further discussions on best plan for use of shades)

The values in Table 2 2 (measured by pyranometer as langley/cm^2/day) show the variability from place to place of daily solar radiation cycles during the summer months and their change with season For example, the 2 stations in Florida were highest in May, but from June to August they were considerably lower than the three locations in Texas In the most humid areas (Florida and Louisiana), clouds contribute to the lower values in midsummer The reading of 700 ly/day is taken as a point where the direct radiation would be such as to impose severe stress on an animal The variability of occurrence of this reading by month and location is quite high (Table 2 3) At Forth Worth, Texas, more than half the days in June would be expected to exceed 700 ly, in contrast to 10 days or fewer in the other locations By September and October the incidence of direct radiation would be low at all locations Although the direct radiation levels are highest in June, the total (direct and reflected) would remain high through July and August due to the ground radiation, particularly in a dry area like Fort Worth, Texas

The economic feasibility of providing animals protection from

TABLE 2.2
Average daily solar radiation (langley/day) by months for several locations in the southern United States.

Station	Apr.	May	June	July	Aug.	Sept.	Oct.
Apalachicola, Fla.	577	628	629	566	518	431	454
Tampa, Fla.	594	650	603	561	535	470	425
Jeanerette, La.	553	604	651	538	530	530	492
Lake Charles, La.	523	586	635	538	543	491	443
Brownsville, Tex.	507	576	647	643	598	498	449
Fort Worth, Tex.	553	621	702	667	632	564	456
San Antonio, Tex.	507	590	649	652	627	531	461

Source: Johnson *et al.*, 1959.

TABLE 2.3
The percentage of time the langley/day would be expected to equal or exceed 700 langley/day.

Station	Apr.	May	June	July	Aug.	Sept.	Oct.
Apalachicola, Fla.	14	34	31	20	0	0	0
Tampa, Fla.	20	33	30	18	6	1	0
Jeanerette, La.	24	30	39	19	12	0	0
Lake Charles, La.	15	28	36	12	4	0	0
Brownsville, Tex.	3	22	37	40	33	1	0
Fort Worth, Tex.	24	43	64	49	28	3	0
San Antonio, Tex.	12	31	39	33	15	2	0

Source: Johnson *et al*, 1959

solar radiation depends largely upon the intensity of the enterprise. As is true for temperature and humidity, exposure to the sun has a greater effect on animals fed for high levels of performance than on animals on lower levels of feeding.

One frequently misunderstood aspect of the solar radiation problem is the importance of skin and hair coat color in reflectivity capabilities. Toward long infrared (thermal) radiation, the skin or hair coat of an animal, irrespective of color, behaves as a "black body"; that is, it absorbs all the incident radiation. Toward shortwave (visible) radiation, hair and skin surfaces vary in reflectivity depending on color. Most of the reports of differences in reflectivity for animals with different color hair and skin have taken into consideration only a portion of the light spectrum with little allowance given to the longwave radiation which is responsible for the greatest part of the radiant heat load in the natural environment. This topic is discussed further in the section on heat regulation (Chapter 3).

Types of Instruments

The most suitable instrument for measuring radiation depends upon the kind of radiation to be measured, such as ultraviolet, visible, near-infrared, far infrared or total radiation Therefore, the capabilities of the instrument must be considered The instruments generally used for measurements may be sorted into two groups (1) those dealing with the intensity of direct solar radiation and some of the reflected radiation, and (2) those dealing with all three components—direct radiation, as well as reflected and thermal radiation (long infrared) exchanged with the general surroundings For further details on radiation instruments, see Reifsnyder and Lull, 1965, Gates, 1962, Platt and Griffiths, 1964, *Annals of the international geophysical year*, 1958, and Nat'l Acad Sci , 1971

Recordings of solar radiation are scant in the N-S 30° latitudes This is due to the high cost of instruments This means that some other measure must be used, such as hours of sunshine per day. Solar intensity can also be estimated from cloud cover, which, as determined from standard classification tables in conjunction with standard meteorological tables, will permit fairly reasonable estimates of the amount of radiation (Critchfield, 1966) A light meter, used in conjunction with cameras, may also be useful for giving reasonable estimates of solar radiation This type of light meter responds only to the visible portion of the solar spectrum and measures in foot candles (illuminance of 1 lumen/ft^2) If the visible portion of the light spectrum is assumed to be a constant proportion (43% of the direct radiation), an estimate can be obtained of the total direct solar radiation, but not of the reflected or thermal

Air Movement

Importance

The rate at which air moves over the skin of an animal affects the rate of heat loss from the body surface This is a relatively simple process on bare skin, but hair, wool, or feathers complicate the process Increased air flow will help heat loss by evaporation when moisture is present on the skin, but when the moisture supply is low, the effect on the animal is limited At moderate temperatures, the more rapid the air movement, the more rapid the loss of heat, at high temperatures (29°C or higher) the reverse may be true Air movement aids in heat loss from the skin by conduction as long as air temperature is lower than skin temperature But when the air temperature is

higher than skin temperature, the skin will gain heat from the surrounding air. And increased air movement will only raise this gain. An increase in air flow will often have the same effect as a rise in air temperature, and increased air movement will also indirectly affect the amount of radiant heat an animal receives by altering the temperature of surrounding objects.

Characteristics of Air Movement

Air flow is usually described as directional or turbulent (rotational). Air flow in a hot, dry area should ideally remain around 8 kmph or less during the day to prevent excessive drying and heating of the animal's body. But after sunset, a rate of 8–16 kmph would help to speed restoration of the animal's heat balance, provided the night air temperature did not drop to the point where an excessive amount of heat would be drawn from the body. Generally, in hot, dry climates the characteristic rate of air movement is undesirably high for livestock indicating that consideration should oftentimes be given to providing some means of protection. In hot, humid environments, on the other hand, low air movement is characteristic; consequently, air movement below 5 kmph and even the small irregular movements should be of concern. For instance, cattle, sheep, or swine kept in a small lot surrounded by a board fence, rather than a wire fence, will lose much of the benefit of the minor air movement. For this reason the provision of shade for livestock is of questionable value in the real humid regions because the congregation of animals may so reduce air circulation, and thus restrict heat loss by evaporation and convection that the net effect of shade will be nil.

The low rates of air movement are the most valuable indicators of animal comfort. They are also the most difficult and expensive to measure since they are near or below the range of most standard recording equipment. In general, there is little need for concern about flow rate in the 8–20 kmph range and there are no serious problems encountered until the rate exceeds 30 kmph. Beyond this point, protective methods are of concern in both hot, dry and hot, humid areas.

Near the equator is an area of calms, known as the doldrums. In this zone, little air movement can be relied upon unless it is created by local topography such as mountains. To the north and south of the doldrums lie the two trade wind belts, in which the wind blows persistently, especially over oceans, at mean velocities of 16–32 kmph, according to season. The trade wind belts are major contributors to the

seasonal air movement patterns in the N-S 30° area The Gulf Coast area of the U S represents the northern belt of influence in the western hemisphere The "trades" blow from the northeast in the northern hemisphere and from the southeast in the southern hemisphere Over the continents in the summer, these trade winds are usually replaced by winds blowing toward the center of the continent on all sides

The local topography frequently dominates wind patterns Valleys tend to channel air movement to their own axes, while contours opposed to the directional flow of air produce upcurrents on the windward side, reversed eddy currents over the crest on the leeward side, and calms at the base of the leeward side when the slope is steep These features of the topography can be useful in the placing of animal shelters Since winds shift direction with season and time of day, these shifts need to be taken into account in determining the suitability of hills versus valleys for day and night grazing

In addition to the impact of air movement on the conductive-convective heat loss of the animal, there is a psychological aspect to consider where extremes are likely to occur—for example, blowing rains in the wet tropics or monsoon belt or high air velocities over dry areas Where dust storms may persist for several days, sheep will huddle and avoid grazing In their struggle to move toward the center of the huddle, animals may be trampled or smothered Dust storms are thus a major worry for sheep herders in parts of North Africa and Middle East

Results from experiments in southeast Georgia showed that during a blowing rain lactating cows without shelter made the best of the situation and continued to eat, while cows with access to a shed enclosed on three sides refused to cross a short open space to a feeding area enclosed on two sides This meant the hay and silage consumption of the sheltered group decreased as much as 50% per day during periods of inclement weather

Measurement

Most meteorological stations are equipped with a wind observation unit consisting of a wind vane and anemometer mounted at the top of a support column The wind vane indicates the wind direction, and the anemometer, the force of the wind

For further details on instrumentation for measuring rate of air movement, see the National Academy of Science publication (1971) A convenient scale for estimating rate of air movement in the field is shown in Table 2 4

TABLE 2.4
Scale for estimating rate of air movement.

Description	*Rate (kmph)*	*Behavior of objects*
Calm	Less than 1	Calm; smoke rises vertically
Light air	2–5	Direction of wind shown by smoke drift but not by wind vanes
Light breeze	6–11	Wind felt on face; leaves rustle; ordinary vane moved by wind
Gentle breeze	12–19	Leaves and small limbs in constant motion; wind extends light flag
Moderate breeze	20–29	Raises dust and loose paper; small branches are moved
Fresh breeze	30–39	Small trees in leaf begin to sway; crested wavelets form on inland waters
Strong breeze	40–50	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty
Very strong	51–62	Whole trees in motion; inconvenience felt in walking against wind
Moderate gale	63–74	Breaks twigs off trees; generally impedes progress
Fresh gale	75–87	Slight structural damage occurs (roof shingles removed)
Strong gale	88–101	Seldom experienced inland; trees uprooted; considerable structural damage
Whole gale	102–117	Very rarely experienced; accompanied by widespread damage
Hurricane	120 & over	God bless us all!

Rainfall

Importance

The major influence of rain on livestock in the N-S 30° areas is indirect, the result of its influence on feed supplies and on disease and parasitism.

In some parts of the tropics, the intensity of the rainfall is so high

at times that the soil cannot possibly absorb the rain as it falls The amount of rain falling in a given time, its duration, and the condition of the soil all influence the amount of water that will go into the subsoil beyond the normal root depth for the vegetation The extent to which soil moisture is available for crop production depends not only on the total annual rainfall but also on the seasonal distribution and the intensity of the rainfall, the condition of the soil, the vegetation cover, and the rate of evapo-transpiration

To the livestock producer the seasonal rainfall pattern is very important because it determines (1) the amount of feed that can be produced, (2) the length of time forages maintain high quality, (3) the grazing practices that can be employed, (4) the requirements for stored and supplementary feed supplies, and (5) the type of feed preservation system that will be most useful Periods of heavy rainfall increase the water content of the forages, thereby limiting the amount of nutrients the animal can obtain because of the physical limitations on total intake

Table 2 5 shows the monthly distribution of rainfall at Jeanerette, Louisiana, and the number of days per month when rainfall is likely to exceed 0 025 cm per day Except for October, the average monthly precipitation is sufficient for crop production The normal season of seeding for hay crops is April–May The temperature, humidity, and amount of rainfall for June and July are conducive to rapid growth For peak quality hay, it should be cut in late June or early July, but in July the probability of getting 3 or more days in succession of good drying weather is less than 10% Since the high level of humidity prevailing at that time accentuates the problems, the opportunities for making hay from June through August are restricted Based on rainfall distribution, October would be the best time for hay making, but by that time the plants would be so mature that the quality of the hay would be poor The probability for obtaining better quality by ensiling the crop would be much better Even so, it would be best to get the crop ensiled before July or after mid-August to maximize the probability of getting good quality material The planting should be scheduled so that time of harvest will correspond to the period at which the weather is most likely to be satisfactory for handling the crop For further discussions of rainfall in relation to handling feed supplies, see Chapters 6 and 14

Another aspect of rainfall important in long range planning, as well as season to-season practices on feed supplies is rainfall reliability Figure 2 4 shows the variation in annual rainfall over a 20-year period at Jeanerette, Louisiana and Nagpur, India The average annual means are 150 and 127 cm, respectively, but the variation

TABLE 2.5
Average rainfall (1953–1967) and number of days per month with rainfall >.025 cm by months at Jeanerette, Louisiana (29°56′north latitude, 8 m elevation).

Months	*Rainfall (cm)*	*No. days/month with .025 cm or more*
January	11.7 ± 5.9	5 ± 2.4
February	14.2 ± 8.8	7 ± 2.8
March	8.6 ± 5.8	5 ± 2.2
April	11.7 ± 6.9	5 ± 2.2
May	12.4 ± 6.7	6 ± 1.9
June	17.3 ± 7.8	9 ± 3.0
July	24.1 ± 8.8	14 ± 3.3
August	20.8 ± 8.3	12 ± 4.8
September	13.2 ± 6.7	8 ± 3.0
October	6.9 ± 5.7	4 ± 2.5
November	8.1 ± 5.0	5 ± 2.1
December	14.2 ± 8.3	7 ± 2.1

among years could mean the total loss of feed supplies in same year, from either excessive moisture or drought. In the year with 229 cm rainfall at Jeanerette, neither silage nor hay could be prepared. Many of the cattle had to be sold before the end of the cold season because of a feed shortage. The incidence and losses from anaplasmosis and parasites were above average that year. From 1950 to 1952 in the area around Nagpur, more than half the livestock died from lack of feed. These are the extremes but, exclusive of the absolute extremes, the variability from year to year is likely to be such that allowances for number of animals, planning for stored feed, and possibly providing supplementary feed from other sources must be considered. The variation among years is small in the wet tropics, and therefore not of much concern; but in the other regions it is a major factor in planning.

Infective agents are affected by rainfall in various ways. Many free living organisms flourish only within fairly narrow ranges of humidity and are thus affected adversely both by too little precipitation and by too much. Other free living agents may, however, be water borne, such as parasites that require an intermediate host like the snail, that is aquatic itself, but is dependent upon precipitation for its complete life cycle.

Rainfall also has important direct effects on livestock. It may help in heat dissipation through evaporation but at the same time seriously interfere with feeding and increase health problems. Animals react

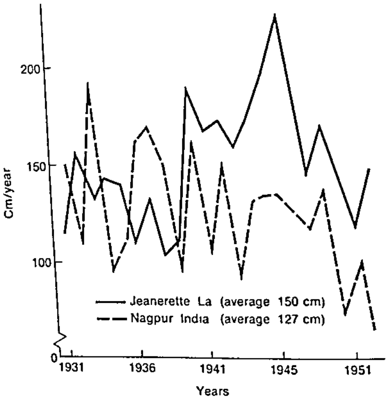


FIGURE 2 4
Variation in annual precipitation at Jeanerette Louisiana and Nagpur, India

more strongly than man to the physical impact of rain, hence they will cease to graze and either stand or leave the grazing area for the protection of trees or knoll This is especially the case if the rain is driven by wind When the forage is very wet following a rain, intake will be somewhat lower than normal

In a hot environment, rain falling upon or retained by the hair coat will evaporate thereby mitigating thermal stress The magnitude of the cooling effect will depend upon the depth to which water penetrates the hair coat and this in turn depends upon the structure of the pelage Wool prevents water from reaching the skin unless the rain is extremely heavy Long hair also reduces the penetration For example, the yak of Asia and Highland cattle of Britain have coats like roof tiling—long hairs projecting beyond underlying longer ones—that shed water easily

Rainfall is closely related to level of humidity and is, therefore, a factor in sheep husbandry British mutton breeds, for instance, do not normally thrive in a hot, wet climate due to the moisture holding capacity of the heavy wool coat However, sheep are among the most

suitable species for hot, dry climates since wool gives added protection against the radiant heat load. Although the alternative uses for land are a factor in restricting sheep production, largely to areas of 50 cm of rainfall or less, rainfall and humidity are of primary importance in limiting sheep to the dry regions of the tropics.

Measurement

Certain information about rainfall can be obtained by visual observation, i.e., its duration and intensity. Rainfall patterns may serve as a crude scale for estimating humidity. The rain gauge is the instrument most frequently employed to measure rainfall (Nat'l Acad. Sci. 1971). Routine recordings of rainfall are available from more areas than are recordings of any other climatic element. Day-by-day levels may vary within a relatively small area due to shiftings of local clouds, but monthly or annual totals can be very reliable for determining patterns in a sizeable area—unless of course, there are large interferences, such as high hills or mountains. Extrapolations from coastal areas to inland areas cannot be made with any degree of satisfaction, however.

To develop a more complete understanding of the sources or causes of rain and the factors contributing to rate of evapo-transpiration, one or more books dealing with climatology should be consulted (Critchfield, 1966; Griffiths, 1966; and Riehl, 1954). Publications such as Great Britain Meteorological Office (1958); U.S. Dept. Commerce Weather Bur. (1965–66); and Wernstedt (1961), are useful sources of rainfall data for many areas of the world.

Light

The period of light during the day is called the "photoperiod" and is defined as the time between sunrise and sunset, or between the beginning of morning civil twilight and the end of civil twilight, which refers to a sun angle of $\pm 6°$. Photoperiods vary with latitude and season. Tables for determining local photoperiods can be obtained from meteorological centers or easily calculated since the rate of variation is directly related to the path of the sun. The length of daily photoperiod near the equator varies only a few minutes but is ± 2 hours at 30° latitude, and as high as ± 19 hours in June at 60° latitude.

The daily photoperiod is critical for plants and has direct influence on animal performance. Sheep is the species of farm animal most

affected by changes in photoperiod. Seasons of high temperature and long photoperiod influence the reproductive patterns through anestrus and decreased fertility in females and decreased semen quality and sperm production in rams. Apparently, light acts on the pituitary gland through neuro pathways from the eyes.

Some researchers believe that length of photoperiod may have indirect effect on animals, through increased wakefulness and metabolic activity, that change levels of feed intake. This has been extensively explored with poultry and it is now standard practice to extend or remove seasonal changes in the photoperiod by artificial lighting especially for laying hens. However, there is little information concerning the effects of light on appetite in other species. Nevertheless the strong sunlight during midday may be an additional factor in making cattle and sheep seek shade, but this has not been demonstrated experimentally.

Research conducted in Australia has shown that the length of photoperiod influences the growth and shedding of the hair coat in cattle. Some researchers have suggested that when temperate zone cattle are moved into the tropics, the small variation in photoperiod often fails to stimulate coat shedding, leading to progressive degeneration and eventually death. Poor nutrition and internal parasites are no doubt the primary causes of lack of shedding for cattle newly introduced to the tropics, but photoperiod could be a contributing factor.

Cloud Cover

The importance of cloud cover has already been touched on several times. Its extent and persistence has a direct, as well as indirect, effect on the animal's environment in warm climates. These have also been discussed. Cloud cover has been given a separate subheading here primarily to serve as a reminder that it can be used to estimate levels of solar radiation and humidity, thereby indirectly indicating to some extent the distress periods for animals.

Atmospheric Pressure

Atmospheric pressure is another element that should be mentioned, as changes appear to have some direct bearing on animals. The prevailing atmospheric pressure is measured with a barometer and is generally referred to as "barometric pressure." The large pressure changes that occur with changes in altitude are especially important

to animals. When they are moved from low elevations to high altitudes, they often encounter difficulties. The reverse is also true. Brisket disease (high mountain disease) frequently occurs in cattle following sudden large changes in altitude. Furthermore, the pressure changes that accompany storms may affect birds, insects, and animals. It has been suggested that animals sense storm conditions from the pressure changes and make modifications in behavior. It has been postulated that declining atmospheric pressure may stimulate feed intake. In Montana, a comparison was made of (*a*) the milk yields of Holstein cows during periods of normal feeding and (*b*) their milk yields during periods in which adjustments were made in the amount of feed offered based on the barometric pressure prior to feeding time. When the pressure was high, part of the regularly offered feed was withheld. This was added to the scheduled feedings when the pressure declined. The cows fed on the "adjusted basis" consumed more feed, produced more milk, and showed less variability in production than animals receiving a constant daily allowance. As yet the evidence on the effects of pressure changes on animal performance is very limited, but much more attention may be given to this subject in future research. It is common practice to make adjustments for atmospheric pressure in biological research. To date, measurement of atmospheric pressure is used primarily in connection with weather forecasting since it is essential to the understanding of winds, storms, and related atmospheric phenomena.

CLIMATIC CLASSIFICATIONS

There are numerous possible classifications for climate, but the value of each depends largely on the purpose for which it is intended. A classification of climates as they might affect jet aircraft certainly would not indicate ground level climatology for plants and animals, therefore, the number of classifications of climate about equals the number of problems. Even when the same climatic elements are involved their relative significance and best means of expression are also likely to vary with the problem. Classifications suitable for ascertaining the physical environment for plant growth are not the best for determining animal husbandry practices.

The most widely used system of classification of world climates is based on the work of Köppen, who aimed at a scheme that would relate climate to vegetation but at the same time provide an objective, numerical basis for describing climates in terms of climatic elements. The Köppen system recognizes five major climatic types (Table 2.6)

TABLE 2.6
A[illegible] of Koppen classification of climates

Major types		Main subtypes	
Symbol	Characteristics	Symbol	Characteristics
A	Tropical rainy temperature > 18°C	Af	Tropical rainforest hot rainy all seasons
		Am	Tropical monsoon hot seasonally excessive rainfall
		Aw	Tropical savanna hot dry winter
B	Dry evaporation exceeds precipitation	BSh	Tropical steppe hot semi arid
		BSk	Mid latitude steppe cool or cold semi arid
		BWh	Tropical desert hot arid
		BWk	Mid latitude desert cool or cold arid
C	Mild temperate rainy temperature coldest month < 18 C but > −3°C	Cfa	Humid subtropical mild winter long hot summer moist all seasons
		Cfb	Marine mild winter warm summer moist all seasons
		Cfc	Marine mild winter short cool summer moist all seasons
		Csa	Interior Mediterranean mild winter hot dry summer
		Csb	Coastal Mediterranean mild winter short warm dry summer
		Cwa	Subtropical monsoon mild dry winter hot summer
		Cwb	Tropical upland mild dry winter short warm summer
D	Cold snow forest temperature coldest month < −3 C warmest month > 10 C	Dfa	Humid continental severe winter long hot summer moist all seasons
		Dfb	Humid continental severe winter short warm summer moist all seasons
		Dfc	Subarctic severe winter short cool summer moist all seasons
		Dfd	Subarctic cold winter short summer moist all seasons
		Dwa	Humid continental severe dry winter long hot summer
		Dwb	Humid continental severe dry winter warm summer
		Dwc	Subarctic severe dry winter short cool summer
		Dwd	Subarctic extremely cold dry winter short cool summer
E	Polar	ET	Tundra very short summer
		EF	Perpetual ice and snow
		H	Undifferentiated highland climates

which are intended to correspond to five principal vegetation groups. In order to represent better the types of climate, additional symbols were added to designate the main subtypes (Table 2.6). Except in the dry climates, the second letter refers to rainfall regime and in the B, C and D grouping a third letter is used to describe special features of temperature characteristics. Köppen also provided a fourth set of symbols which he used to describe special features of the climates beyond those shown in Table 2.6; therefore, a great number of subdivisions are possible.

With Köppen's classification as a general base, numerous other classifications have been presented since the mid-1930's. One of the more prominent of these was by Thornthwaite (1948), who used a moisture index defined as the potential evapo-transpiration; his classification applies primarily to botanical needs. The map of the world distribution of climatic types prepared by Thornthwaite and one prepared by Trewartha (1954) that is also based on a modification of the Köppen system are useful in estimating growth rate and probable broad seasonal variations in feed supplies from natural grasslands, but as will be seen later it is desirable to have more extensive characterizations of local ar regional climates for best decision making for animal management.

Lee (1953) recognized the inadequacy of the two previous classifications for expressing distributions of climates in relation to their significance for man and animals. He proposed that a more suitable approach for animals would be to designate regions based on the temperature and humidity prevailing in the warmest and coolest months. The warmest month was defined as that following the summer solstice for regions outside the solar tropics, and that following the second zenith passage of the sun for areas within the tropics. The coolest month was defined as the one following the winter solstice. Temperature and humidity conditions were classified as follows:

Temperature:

Mean temperature of months:	Over 30°C – hot
	20–29°C – warm
	10–19°C – temperate
	Under 10°C – cool

Humidity (warm and hot periods only):

Mean dew point of month:	Over 20°C – wet
	16–19°C – humid
	Under 15°C – dry

TABLE 2.7
Two systems of classification of tropical climates

A Williamson and Payne's Classification

Climate	*Vegetation*	*Soil*
Super humid	Rain forest	Podsols (gray brown, red and yellow)
Humid	Forest	Laterites
Sub-humid	Grassland	Chernozems and degraded chernozems
Semi arid	Steppe	Chestnut and brown soils
Arid	Desert	Sierozems and desert soils

B Webster and Wilson's Main Climates of the Tropics
- Wet equatorial climates
- Dry tropical climates
- Monsoon climates (alternately wet and dry tropics)
  - *a* Areas with 100–200 cm precipitation/annum falling in two rainy seasons
  - *b* Areas with two short rainy seasons and pronounced intervening dry seasons
  - *c* Areas with one fairly long rainy season usually 76–125 cm and one long dry season
  - *d* Areas with one short rainy season and one long dry season
- Wet climates of tropical windward coasts
- Dry climates of tropical and subtropical west coasts

Source A, adapted from *USDA Yearbook, 1941* B adapted from Webster and Wilson 1966

Mapping of areas according to this system of classification makes it clear that any attempt to divide the world into 20 or 30 regions would obscure the variability that is so vital in determining the likeliness of success or failure with livestock enterprises

Williamson and Payne (1965) and Webster and Wilson (1966) attempted to describe the problems of animal production in the tropics by using the classifications for climates shown in Table 2.7 Williamson and Payne's very general classifications for climate and vegetation create only broad distinctions between areas The breakdown used by Webster and Wilson is somewhat more descriptive but again far too general to give a farmer anything beyond what he already knows

All of these systems of classification have described the climatic patterns created by moisture and dryness, heat and cold But these classifications at best represent only the broadest of guidelines for animal husbandry To these should be added as much meteorological data supplemented with extrapolations from basic principles as can be provided from local sources This would include the use of standard tables for determining factors relevent to radiation, such as prevailing photoperiod and cloudiness

Even if satisfactory data were available for describing the characteristic patterns for all the climatic elements, there remains the problem of how to give proper weightings for the various elements with respect to their influences on the performance of animals. Unfortunately, technology has not advanced to this stage. On the other hand, certain minimum levels at which the influences of climatic elements become significant to animal comfort and productivity have been reasonably established for most groups of livestock. It should be recognized, however, that the minimum point at which animals are influenced will vary with age, stage of lactation, and stage of gestation.

Although it would be desirable to have more extensive knowledge of the expected climatic conditions, from the practical standpoint the expected monthly fluctuations are generally satisfactory since it is not usually feasible to make adjustments in animal management practices more frequently than once a month. More modifications may prove of economic significance with intensive poultry and swine operations, but the advantages anticipated by frequent adjustments with cattle may be offset by the disturbances created. If, for instance, lactating dairy cows are alternated, at one or two day intervals, between a shaded lot and open pasture, or kept on drylot feeding and then shifted to pasture feeding, the fluctuations in feed consumption and consequent variations in milk yield will nullify any benefits of the changes. At present, it appears that decisions about the tropicality of an area can be derived for most practical purposes by the scoring of monthly means for the various elements.

The classifications for temperature and humidity proposed by Lee seem to be reasonably good. But it is difficult to keep both temperature and vapor pressure, or relative humidity scales, in mind as well as ascertain the point of significant interaction between the two elements. The U.S. Weather Bureau has attempted to interpret the two into a meaningful index based on sensations of comfort or discomfort for man, and limited data indicate the index is also suitable for estimating the discomfort of animals. This index is identified as THI (temperature-humidity index). THI values may be calculated from dry bulb plus a measure of humidity such as:

$$\text{THI} = 0.72\,(C_{db} + C_{wb}) + 40.6$$

where db = dry bulb temperature in °C, and wb = wet bulb temperature in °C.

The merit of the temperature-humidity index for evaluation of animal responses has not been extensively investigated. However, studies conducted at the University of Missouri (Johnson *et. al.*, 1963)

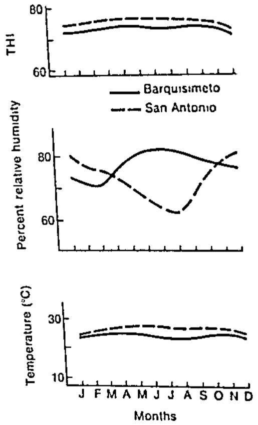


FIGURE 2.5
Comparison of temperature, percent relative humidity, and temperature-humidity index values for two locations in Venezuela

showed that losses in milk production for lactating cows were clearly related to changes in THI. The cows seemed to have little discomfort while the index was 70 or below, but they became uncomfortable and milk yield and feed intake were depressed at 75. Cattle of all ages showed measurable degrees of discomfort at an index of 78 or above, and similar to experiments with man, the degree of discomfort became more acute as the index increased.

The monthly THI values in Figure 2.5 tell more about the temperature-humidity conditions at Barquisimeto and San Antonio, Venezuela than could be grasped from the separate temperature and humidity scales. The wide range in relative humidity levels for 6 months of the year between the two areas is brought into better focus on the THI scale. The mean monthly temperatures for both locations suggest little problem from high temperatures, but when the tempera- tures are combined with the wide variations in humidity, the THI values are 72–75 for the entire year. Based on Missouri investigations, this implies cattle would be under conditions of almost continuous stress at both locations, but for different reasons. Too, the THI's suggest the Barquisimeto area would be warm and humid enough to

provide an almost ideal environment for many types of ecto- and endo-parasites. The humidity level would also be likely to create some problems for sheep.

Since solar radiation can be a significant factor in the animal's environment, an even more satisfactory method of classifying climates for animal husbandry practices would be according to what is termed an "effective temperature" (ET) scale, which incorporates into one index proportionate weightings for temperature, humidity, and solar radiation.

$$\mathrm{ET} = K_a\,(\mathrm{db}) + K_b\,(\mathrm{rh}) + K_c\,(\mathrm{sr})$$

where ET = effective temperature, db = dry bulb temperature, rh = relative humidity, sr = solar radiation, and K_a, K_b, K_c = constants depending upon the units employed. Inclusion of solar radiation theoretically affords additional refinement, but as indicated earlier, there is no satisfactory way of estimating the net heat load imposed on animals by radiation. And the use of arbitrary values, such as those given in Figure 2.3, would hardly seem to justify the extra calculations. Thus, at this stage of technology, attempts to estimate ET values for a location are not warranted.

Although much more research is required to develop satisfactory systems of climate classifications for use with livestock, utilization of the currently limited data together with certain correlated information will produce more objective classifications than those described in Tables 2.6 and 2.7.

SOILS OF WARM CLIMATES

An assessment of the characteristics of the local soil completes the picture of the animal's physical environment. Although almost any type of soil can be found in the warm climates, in general the soils there have less natural fertility than in the higher latitudes. Judgments of the agricultural potential of tropical soils are as varied as the backgrounds of those who appraise them. They range from dismal pessimism to strong optimism. The pessimistic viewpoints are documented by records of actual performance, principally the ineffectual struggles of peasant farmers against physical, biological, and economic forces. The optimistic projections are based on resources of sunlight energy and water, and on the successes achieved by people having full access to science and industry.

Potential fertility is frequently judged by the vegetation present. However, this can be misleading. For instance, the heavy vegetative growth in a jungle area may seem to indicate high soil fertility and high potential for crop production, whereas this abundant growth is actually dependent upon the ever present high level of organic matter distributed by the plants. If the cover is removed and the land cropped, the fertility decreases rapidly, leaving a soil too poor for agricultural production. Cleared jungle areas can be cropped for a year or two, but thereafter they must have heavy applications of fertilizer for satisfactory crop production.

The types and conditions of local soils depend upon (1) climatic conditions, (2) the nature of the parent rock, (3) the age of the soil, (4) the topography, and (5) the biological activity present, including that imposed by man's agricultural practices. Two features distinguish the soils of the warm climates. For the most part they are old, that is they have weathered to the point that the parent rock is deep or soft and will crumble with relative ease. Also, their level of organic matter is low. The leaching of organic matter and weathered condition resulted from rainfall and warm temperature conditions. Loss of organic matter by leaching has led to physical deterioration of the soils and loss of nitrogen.

The weathered soils represent the greatest proportion of the region because of topography and erosion from runoff of rainfall. The exception to the weathered soils are those from volcanic ash, e.g., in Hawaii. These are still rich soils even though subjected to high precipitation and high temperatures during certain periods of the year. The volcanic soils are, of course, younger in formation than the soils of the continents.

Lateritic soils of red to brown clays formed by weathering under monsoon climates are characteristic of large portions of both the tropics and subtropics. The arable lands with these soils have fair to excellent physical properties, but they are low in plant nutrient reserves, e.g., nitrogen and phosphorus, including micronutrients, e.g., zinc. Those soils with residual silica or granite are poor, especially in the micronutrients. In general, the natural fertility of the lateritic soils is rather low, nevertheless, experiments have shown that crops respond well to fertilization of these soils, combined with other needed practices. A combination of practices must be stressed. For example, in the Casamance Valley in Senegal, plans were made for peanut production on a large scale employing mechanized clearing of the wooded savanna. The clearing operation and subsequent deep plowing exposed subsoil that had poor structure and was relatively

infertile. Yields were below expectations and rate of erosion was high since the mechanical clearing had removed practically all the roots of trees and plants. The project was abandoned after three years.

By contrast, in tropical Australia, Puerto Rico, and Brazil combinations of practices have met with success, notably the introduction of legumes into grass stands in Australia, heavy applications of fertilizer and lime in Puerto Rico, and the use of some fertilizer with supplementary irrigation in Brazil (Sci. Advisory Comm., 1967).

There are two types of soil generally characteristic of semi-arid regions: (1) black earth, which contains a high percentage of organic matter, and (2) chestnut earth, which is high in calcium carbonates, sodium salts, and gypsum, but relatively low in organic matter. In the arid regions, the soils are formed from mechanically disintegrated rock with little chemical decay and very low organic matter content. If water can be supplied, the fertility of these soils is generally high, but salinity may become a problem unless adequate drainage is provided. However, loss of organic matter by leaching is not a problem due to the low rainfall.

From these brief comments, it should be clear that it is highly desirable for successful livestock husbandry to know the local soil characteristics, particularly with respect to the probability of mineral deficiencies. Of equal significance for appropriate management is a knowledge of the rainfall patterns. Soil maps prepared by FAO on a world-wide basis are incomplete at this point, but they can still be very useful. The Soil Conservation Service of the U.S. Department of Agriculture is also a good source of soil maps for the greater portion of the world. In addition, there are ordinarily one or more governmental agencies of most countries devoting time and effort to characterizing the soils. These should be sought out. Further points relative to soils and forage production are dealt with in Chapter 6.

PROFILES OF PHYSICAL ENVIRONMENTS

The term "profile" is used instead of "classification" to accentuate the need for considering more than the extremes of climatic elements in assessing the physical environment, as portrayed in Figures 2.1 and 2.2. The profile that can be developed for a location will, of course, be largely dependent upon the extent of information available.

If there are no climatic data available for an area, examination of world climatic maps in one of several good atlases can be a start.

Checking the Koppen classification for the area may also prove helpful On the spot surveys of the types of livestock in the area, the use being made of the livestock, the degree of fatness of the animals, and the conditions of the crops, are quite useful in identifying the local problems Discussions with local residents regarding animal diseases and parasites, age of marketing of the livestock, cropping patterns, forages native to the area, and approximate crop yields are also quite useful Knowledge of the elevation and latitude of a location is often valuable in drawing on information from other areas that have been more extensively characterized

The approximate sequence of priorities recommended for further refining the profile are as follows

(1) Mean monthly temperatures will aid in determining tropicality on the basis of the number of months the means are 24°C or above

(2) Mean monthly maximum and minimum temperatures will help to characterize the extremes, as well as aid in deriving estimates of the rate of diurnal heating and cooling

(3) Monthly precipitation, coupled with temperature data, will aid in characterizing the expected growing season for plants, estimating the rate of plant growth and maturity, determining the extent of the period(s) of shortages of moisture, and provide general estimates of the prevailing humidity conditions Information on the duration and intensity of rainfall is also highly desirable

(4) A measure of mean monthly values for humidity (relative humidity, vapor pressure, or dew point) will enable predictions on cropping plans, type and location of housing, and problems of disease and parasitism

(5) The rate of air movement and prevailing direction, particularly with respect to duration of extremes (<5 kmph or >25 kmph) will aid in planning the need for introducing mechanical means of increasing air flow or on decisions regarding the need for protection of the animals from high velocities

(6) Mean monthly radiation estimates, made either from direct measurements, from hours of sunshine, or from cloud cover will aid in defining shelter needs and feeding plans

(7) The mean monthly photoperiods are particularly useful in the management of poultry and turkeys, and to some extent in the management of breeding of sheep and buffaloes

(8) Calculation of temperature-humidity index values by months provides a further refinement of the interactions of these elements

that is helpful in decision making on ventilation of housing and whether it is best to attempt storing forages as hay or silage.

(9) Of course, the most complete and hence most valuable profile would encompass estimates of the proportion of the average day in each month for which it is expected that:

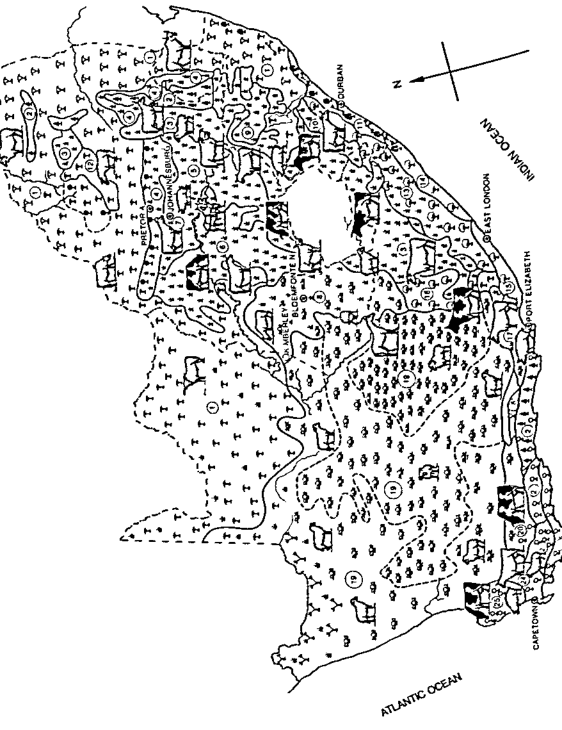
(a) dry bulb temperature will exceed 27°C;
(b) dew point temperature will exceed 21°C or relative humidity will be 60% or higher;
(c) solar radiation (langley/day) will be expected to equal or exceed 700 langley/day;
(d) air movement will likely be less than 5 kmph or greater than 25 kmph;
(e) the number of days rainfall may be expected per month is also desirable, particularly if intensive livestock enterprises are anticipated.

Other information needed to complete a profile of the physical environment includes the soil characteristics, especially soil type and pH, and recorded observations on the incidences of prevailing diseases and parasites. The latter are essential for determining general management practices and developing vector control and vaccination programs.

One of the most important elements of the environment, which is depicted in Figure 2.1 but not included in the list, is the feed supply. Knowledge of currently available feed supplies is a primary requisite of livestock management but it has been excluded from the list because a main objective of developing profiles is ability to use the information in plans for the production and handling of feed supplies. The profile also serves as the basis of determining which animal husbandry practices will be economically feasible.

Few areas of the world have been characterized as suggested. This is particularly true with respect to animal production. The first reaction to such an extensive profile is a pessimistic one; is it worth the effort? The failure of most of the dairy development schemes in India to meet their goals set for milk supplies can be attributed in part to the planners failure to fully appreciate the limitations imposed by the physical environments.

On the other hand, development of a detailed profile for a location in southern Louisiana led to reorientation of methods of crop production to such an extent that the lactation milk yields per cow were increased more than 40%, through use of better roughages. Cor-


N
INDIAN OCEAN
DURBAN
EAST LONDON
PORT ELIZABETH
BLOEMFONTEIN
CAPETOWN
ATLANTIC OCEAN

2. *Forestry region*

3. *Semi-intensive Sourveld region*

4. *Tall Grassveld mixed farming regions*

5/Intensive cropping and livestock production region

6. Semi-intensive cropping and livestock production region

7. Intensive urban livestock production region

8. Semi-extensive transition region

9. Mixed semi-intensive livestock production region

10. Intensive mistbelt

11. Sub-tropical sugar belt

12. Semi-intensive cattle farming region

13. Semi-intensive mixed farming region

14 Intensive mixed farming region

15. Intensive mixed farming region

16. Stud cattle farming region

17. Irrigation and mixed farming region

18 Deciduous fruit growing region

19. Sheep farming regions

20. Irrigation region

21. Semi-intensive mixed farming region

22. Wheat and dairy farming region

23. Semi-intensive coastal region

24. Mixed intensive livestock and winter cereal region

25. Wheat and intensive livestock production region

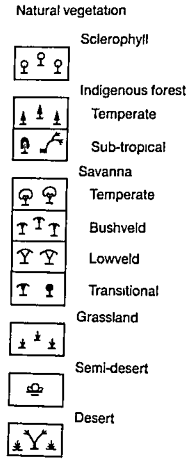


FIGURE 2.6
Regional projected development of animal production for South Africa based on environmental profiles determined from rainfall, temperature, topography, soil, natural vegetation, and types of animals available (Adapted from Bonsma and Joubert, 1957).

average length of calving interval for the dairy herd was reduced about 12%, the need for importing feed supplies from outside the area was reduced, and the unit of land required per animal lowered 40% The profile best served to determine the most satisfactory systems for handling feed supplies and developing plans to minimize the impact of internal parasites The level of inputs per animal unit was increased under the revised system, but the unit cost of milk yield was markedly reduced over that for a combination of permanent pasture and concentrate feeding

In an area of northern Colombia, a profile based on local surveys and the first three items in the list, namely, mean monthly temperature, maximum and minimum temperatures, and precipitation patterns, provided the basis for development of a system of calf housing, feeding, and parasite control that aided in reducing calf mortality from over 40% per year to less than 10% It also helped determine the most suitable season for planting and harvesting corn for silage The best season proved quite different from the customary practices

The Union of South Africa is one of the few countries that have developed a country wide profile for livestock production (Bonsma and Joubert, 1957) In developing the profile, the distributions of rainfall, temperature, topography, soil, natural vegetation, and animal disease problems were determined from data collected by the various agencies of the South African Department of Agriculture for the entire country After careful study, 25 regions were established, each with some peculiar problems related to its potential for livestock (Figure 2 6)

South Africa has already realized a number of benefits and will no doubt realize many more over the coming years Thus far the profile has served as a base for the identification of problems and establishing priorities for research in animal science It has been the guideline on the allocation of government funds for producer incentive programs The profile has proven very valuable to the extension services for animal husbandry in the application of research technology to the farm Weather conditions are monitored within each major zone and projected feeding conditions passed along to farmers

It would be wishful thinking to anticipate that the use of extensive profiles will spread rapidly However, greater understanding of the value of such efforts seems imperative if the projected higher total output of livestock products set forth by food planners and animal husbandry experts is to be achieved Subsequent discussion will further support the worthiness of the time and efforts spent toward characterizing the physical environments

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II

RESPONSES OF ANIMALS TO WARM ENVIRONMENTS

3

The Animal Body in Warm Environments

From the previous chapter's description of the climate conditions predominating in the lower elevations of the N-S 30° latitudes, it is evident that due to level of one or more of the climatic elements, conditions lie outside the present best estimated range for optimum efficiency of livestock. The fact that several species of livestock are found even in the areas with the most extreme climatic conditions means the animals, through one means or another, have managed to meet the challenges of the environment sufficiently to at least survive. But more than survival is required to provide a reasonable return from inputs of feed and labor.

Domestic livestock need to maintain a near constant internal environment for survival and for efficient functioning as defined by the livestock producer. An accumulation of excess heat in an animal, brought about by a hot environment, favors deleterious chemical and physical processes. If the excess heat persists, serious degenerative effects may result.

The impact of a hot environment on certain processes and on performance is illustrated in Table 3.1 by a comparison of the average values for a lactating Holstein cow in a comfortable environment

TABLE 3 1
Average values for certain physiological functions and performance of a lactating Holstein cow in a comfortable environment (18°C) and in a hot environment (30°C)

Trait	*Comfortable*	*Hot*	*% difference in hot environment*
HEAT PRODUCTION			
Metabolic heat production (kcal/hr)	841	629	−25 2
Thyroid secretion rate constant	006	004	−33 0
RESPIRATION AND BODY TEMPERATURE			
Rectal temperature (°C)	38 6	39 9	3.3
Skin temperature (°C)	33.3	37 9	13 8
Respiration rate/min.	32.0	94 0	194 0
Respiratory volume (l /min.)	127 0	239 2	88.3
Tidal volume (l /breath)	3.04	2 74	−9 9
BLOOD			
Volume (cc/kg body wt.)	84.3	91 6	8 6
Glucose (mg %)	56.5	57 2	1 2
pH	7.55	7 63	10.5
Ketones (mg %)	3 1	3 8	22.6
Hematocrit (%)	32 4	31 7	−2.2
Creatine (mg %)	1 08	1 42	31 4
Plasma protein (mg %)	9.5	9 2	−3 1
Plasma CO_2 content (vol %)	53 1	44 3	−16 6
Plasma CO_2 combining capacity (vol %)	55 1	47 7	−13 4
Erythrocytes (million/cm blood)	6 99	6 92	−1 0
Leucocytes/cm blood	9342	9318	−0 2
Red cells 10^2	7013	6646	−5 2
White cells 10^2	99	106	7 1
RUMEN ACIDS			
Total volatile fatty acids (meq/liter)	95 2	85 2	−10.5
Acetic (meq/liter)	59 6	55 4	−7 0
Proponic (meq/liter)	20.8	17 0	−19 0
URINE			
Specific gravity	1 03	1 02	−1 0
pH	8 0	7.9	−1 2
Water intake urine output	5.5	5.8	5 1

TABLE 3.1 (con't)

WATER			
Consumed			
Free (kg/day)	57.9	74.7	29.0
Feed (kg/day)	1.6	1.4	−14.3
Urine volume (kg/day)	11.1	12.8	15.0
Fecal water (kg/day)	17.9	12.0	−33.0
Evaporation			
Surface (g/m²/hr)	94.6	150.6	59.3
Respiration (g/m²/hr)	60.6	90.9	50.0
FEED			
Concentrates consumed/day (kg)	9.7	9.2	−5.1
Hay consumed/day (kg)	5.8	4.5	−22.4
Efficiency (Mcal milk/DE %)	59.0	38.1	−35.4
PRODUCTION AND BODY WEIGHT			
Milk yield/day (kg)	18.4	15.7	−14.6
Milk fat/day (kg)	0.63	0.38	−39.7
Milk solids-not-fat/day (kg)	1.59	1.29	−18.9
Milk protein/day (kg)	0.59	0.49	−16.9
Body weight (kg)	486	482	−0.9

(18°C) and after several hours or days following exposure to a hot environment (30°C). Some measurements reflect marked changes, others moderate changes, and still others little or no change. Of the 40 variables listed, 25 decline under thermal stress and the rest show some increase. The magnitude of the change is, of course, directly related to the level of the temperature conditions, the breed of the animal, its age, stage of lactation and level of feeding. Therefore, the values in Table 3.1 apply to a lactating Holstein cow under the given temperature conditions. The changes for a lactating Holstein would, for the most part, exceed those for a dry Holstein or for smaller breeds, like the Zebu; but the trends would be similar.

The shifts in the variables shown in Table 3.1 may be either direct results of the temperature (e.g., the nearly 200% rise in respiration rate) or indirect results (e.g., the decline in milk yield caused by reduced feed intake). Whatever the reason, there is a 15% reduction in milk yield and a 35% decrease in efficiency, that is, utilization of energy for productive purposes. This is our major concern.

All domestic livestock have certain means at their disposal to assist them in maintaining homeothermy or minimizing disfunction in homeothermy Some species and breeds within species even have special anatomical characteristics that aid them in withstanding the stress imposed by the hot environment An appreciation of how an animal goes about adjusting to its environment is useful for determining the best ways to improve efficiency of animal performance in unfavorable environments Three chapters are being devoted to this important problem The first deals with the animal's reactions to climatic stress, including the causes and some of the chains of events that determine them The second points to the economic consequences of thermal stress on livestock performance And the third suggests methods to determine whether livestock found in an area or those which could be introduced possess the best features for the level of environmental conditions which can be provided

THE ROLE OF THE HEAT REGULATING CENTERS

An animal's body produces heat continuously, which means it must lose heat to the surroundings if the level of temperature in the body is to remain constant A rise of 1°C or even less in body temperature in most species of livestock is sufficient to produce detectable changes in a number of physiological processes and to reduce performance In order for the animal to maintain thermal equilibrium, the net exchange of heat with the surroundings must be in the direction of heat loss To maintain body temperature within narrow limits requires sensitive and quick acting mechanisms which balance any change in heat production by an equivalent change in heat loss, or balance a change in heat lost through one avenue by an equivalent adjustment in the opposite direction through another

Although its functions are not fully understood, it is generally acknowledged that the hypothalamus, or basal part of the diencephalon (interbrain), contains the centers for major control of heat balance in the body It has been demonstrated, by implanting electrodes in the hypothalamus of cattle and goats and applying heat, that centers in the hypothalamus have direct control over some functions and act as an integrating agency for others The experiments with heated electrodes indicate that centers in the hypothalamus respond to impulses from both cerebal hemispheres and peripheral receptors located in the skin surface and other areas

The role played by the heat regulating centers in the hypothala

mus in heat exchange can probably best be envisioned by comparing these centers to the board of directors of a corporation. In a corporation the board, or top management, is concerned with the major decisions and the details of the more critical problems, whereas the lower echelons manage most of the day-to-day operations. For such an organization to function efficiently, two things are essential: adequate information and readily available lines of communication for transmitting commands. Although the hypothalamus often acts as a controlling center, it depends upon signals from both the periphery and the interior of the body, including special motor and vasomotor responses.

The regulation by the hypothalamus of the rate of heat loss from the body involves control over the size of small blood vessels near and in the skin, the action of sweat glands, and the general posture of the body. It also entails the adjustment of other processes to compensate for the initial disturbances. All these mechanisms must receive instructions directly or indirectly from the central heat regulating centers. Although some important executive brain cells have direct lines of contact to tissues or organs under their control, there is no evidence that this is true for the heat regulating centers. It seems more likely they are required to use indirect routes of communication. Nerve fibers run from the heat regulating centers along the spinal cord for varying distances until they make contact, through other nerve centers, with the motor nerves going to the organs or tissues. Most of these fibers belong to the "symphathetic" nervous system, which controls the automatic functions of the body, rather than the "somatic" nerves, which control the voluntary muscles.

In addition to nerve pathways, chemical processes also appear to assist in thermal regulation. For instance, the posterior pituitary gland is concerned, among other things, with maintaining water balance, and thus it is often involved in a secondary way in heat regulation.

MEANS OF HEAT EXCHANGE

The physical processes involved in the exchange of heat between the animal body and its environment are conduction, evaporation, convection, and radiation. Conduction is the passage of heat energy from particle to particle due to temperature gradient. Evaporation is the vaporization of water from the body surface and respiratory tract, which aids in the cooling process. Convection is the transfer of heat energy by the circulation of a fluid or gas at a non-uniform temperature. Radiation is defined as the transfer of energy across space without heating the space through which it passes. With respect to a hot

environment, the main concern is radiant energy from the sun or hot ground Each of the four physical processes has a climatic counterpart —temperature, humidity, air movement, and radiant energy, respectively

Within the comfort range for animals, about 75% of the heat lost from the body is dissipated by conduction, convection, and radiation, but at higher temperatures, evaporation alone may be the major means of heat loss

CONDUCTION

Conduction plays two roles in the animal's heat regulation that of movement of heat from the central body core to the external surfaces and the flow of heat from the skin surface to the surroundings If an animal is standing quietly in an environment between 13 and 18°C, heat is produced in the body at a moderate, uniform rate From the central core of the body, heat passes toward the outer surface, which is of a lower temperature, at a fairly uniform rate The skin in turn passes heat to the environment at a rate dependent on temperature gradient and coat covering (Figure 3 1) If air temperature (T_a) is 13–15°C and body core temperature (I_b) is 39 4°C, the flow to the atmosphere is rapid Some additional heat exchange occurs simultaneously through the respiratory tract so that the animal is in near thermal equilibrium largely by heat loss through conduction When the animal is exposed to T_a 32°C, almost immediately the rate of heat loss from the skin surface to the environment will be reduced and skin temperature will rise As skin temperature rises, the passage of heat from the central core is slowed When this occurs, the production of heat in the body may be reduced or other means of promoting heat loss brought into action

In response to high temperatures the animal frequently tries to bring its body surface into direct contact with a cooler surface, for example, by immersing itself in water The rate and amount of heat loss depend upon the temperature difference between the two surfaces

Conduction also aids in heat loss from internal surfaces that come in contact with the external environment—specifically, the respiratory and alimentary tracts The ambient air going into the respiratory passages comes into equilibrium or near equilibrium with the temperature of the body When air temperatures are in the range of 20–30°C the heat loss by conduction through respiration is of little consequence, but when air temperatures are extremely low or high the rate of heat exchange—loss or gain—via this channel may be significant.

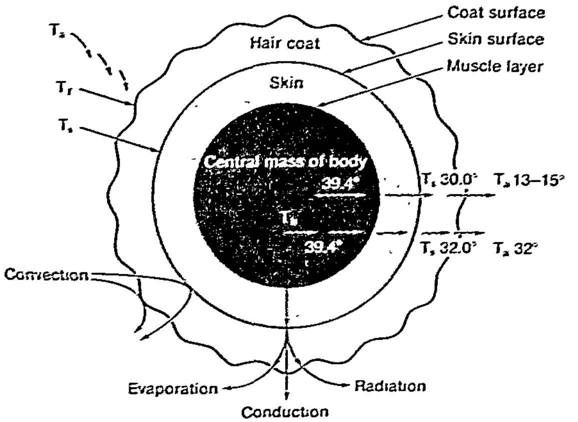

FIGURE 3.1
Schematic of the physical processes of heat dissipation from the animal body and the influence of ambient air at T_a 13–15°C (rapid) and 32°C (low) on the rate of exchange. (T_a, air temperature, T_b = temperature of central core, T_f = temperature of hair-coat surface, and T_s = temperature of skin surface).

The exchange of heat by conduction through alimentary intake depends upon the temperature of the water or food ingested. If a cow consumes 18 kg of 21°C water, about 18 kcal of heat will be utilized to warm the water to body temperature. This will reduce body heat significantly, but a similar amount of water evaporated from the skin surface will remove approximately 16 times more heat.

Evaporation

Heat loss by evaporation takes place from the respiratory tract and from the skin surface. This is the most efficient means of removing heat from the body, as 1.0 gram of water vaporized at 20°C will release 0.6 kcal of heat energy. Water can be made available to the skin surface in three ways: by simple transudation through the superficial layer from the underlying tissues, by activity of sweat glands, and by external applications. The first, which is referred to as "insensible perspiration," occurs relatively independently of external temperature. The second is under control of the heat regulating centers. For

livestock, the external applications of water would include rain, spraying, or the animal submerging itself in water Under hot conditions cats, rabbits, and some other species apply water to their surfaces by licking, but this is not typical of domestic livestock, although cattle or buffaloes will lick or splash water on themselves when under severe stress

The ability of the air surrounding an animal's body to take up vapor from the water present on the skin depends largely upon the humidity of the air If the humidity is low evaporation takes place very readily, but if it is high evaporation will be slow or nil Like conduction, evaporation is markedly dependent upon rate of air flow about the body The thin layer of air adjacent to the skin rapidly becomes equal in humidity with the skin, consequently, further exchange of water vapor by diffusion between the air in contact with the skin and the ambient air will be slow when the air is calm Turbulent movement of the air about the skin accelerates the rate of transfer

A major problem in assessing the rate of heat exchange from the animal body by evaporation is the type and extent of body covering—hair or wool The hair density (number of follicles per unit area), the depth of hair coat (lay of the hair, erect or lying flat), and the oiliness of the hair all influence the rate of evaporation

In the respiratory tract, the temperature of the surfaces from which evaporation takes place into the inspired air stays fairly constant, and the surfaces are sufficiently supplied with water to ensure that the air becomes saturated at that temperature If the inspired air contains only a small concentration of water vapor, as it does in hot, dry climates, the opportunities for evaporation are great Conversely, if the air has a high water vapor content, the rate of evaporation is much slower Rate of respiratory evaporation increases with an increase in the rate and volume of air inspired High respiration rates, such as are induced by heat stress in cattle and sheep, will result in a substantial rate of heat loss in dry air but less in humid air

Convection

Convection facilitates heat exchange both internally and externally—internally, by the circulating blood and externally, by rate of air flow The thin layer of air in immediate contact with the skin rapidly comes into equilibrium with skin temperature Any further exchange of heat between the contact layer and more distant air will be slow in still air, but if there is turbulance in the air, the transfer will be accelerated Since the rate of heat transfer is low unless convection is assist

ing conduction or evaporation, the combined processes are expressed as "conduction-convection" or "evaporation-convection."

With regard to conduction-convection, it is important to keep in mind that convection increases the heat transfer in whichever direction it is taking place. If the flow by conduction is from warmer skin to cooler air, convection will increase the loss; if the transfer is from hotter air to cooler skin, it will increase the gain.

Radiation

This aspect of heat exchange was discussed at some length in Chapter 2. Suffice it to say that heat exchange by radiation can be a very important factor in the thermal balance for an animal exposed to the sun or to reflected radiation from the ground or surrounding objects.

REGULATION OF HEAT PRODUCTION

Upon exposure to a hot environment, the animal reacts initially by activation or acceleration of certain physiological processes to increase the rate of heat loss. If these fail to restore thermal balance, there is a tendency then to reduce the level of heat production in the body by such means as lowered feed intake and decreased activity. Since the amount of heat produced in the body is related to the level of performance, major adjustments in heat production are by and large undesirable.

To appreciate heat production in relation to hot environments and some remedial steps, it is best to divide the metabolic rate and other sources, not by the tissues or organs contributing heat, but by the circumstances which lead to the production of heat. These include the components of the heat produced in the body from: (1) basal body functions, (2) daily maintenance, (3) behavior, (4) performance, and (5) management regime. Since we are concerned with a hot environment, one other component is involved: (6) that extra heat resulting from efforts of thermo-compensation (additional heat produced by increased activities of organs, mainly lungs and heart, to promote heat loss).

The nutritionist and physiologist normally combine the basal, maintenance, and behavior components into a single term, "basic metabolic heat production." They are separated in this discussion because some adjustments can be made in one without necessarily bringing about significant changes in the other.

The heat produced by the basal component comes from those tissues that continue to function even when the body is at complete rest. The main contributors are the heart, lungs, liver, and other organs The amount and rate of contribution by each varies with species and within species by sex, age, body size, stage of gestation, and nutritional state The basal component ordinarily contributes 35–70% of the average daily heat production, depending upon the energy allocated to the other 5 components The energy produced by these processes goes off solely as heat, which must be removed from the body in order to maintain homeothermy The basal component of body heat production may be altered by lowering the basal metabolic rate This would favor the ability of the animal to survive in a hot climate, but the physiological conditions responsible for or accompanying a low basal metabolic rate may so reduce performance (measured as the production of products) that the expected economic advantage would be significantly offset.

The heat from the daily maintenance component is that associated with the production of digestive juices, movements of the alimentary tract, chemical processes of digestion, rumen microflora, absorption of digestive products from the alimentary canal, glandular activities, and other processes associated with maintenance of the living cells of the tissues These functions are sometimes referred to as "specific dynamic action" of the food The contribution from these sources to the total body heat production depends upon general level of nutrition, as well as the type and quality of feeds offered The heat produced from the processing of hay or grass is much higher, for example, than from concentrates

The behavior, or habitual, component also involves the level of basal body functions, but it is given a separate classification because behavior patterns are frequently modified when air temperature rises This component includes the additional heat produced by the animal's customary behavior pattern, whether standing quietly or moving about. The temperament of the animal, or degree of docility, also influences body heat production Highly nervous animals may have significantly higher levels of heat production (Johnson, 1967) The habitual component is oftentimes reduced in a hot environment by decreased pace and general relaxing of muscle tension throughout the body Examples would be drooping of the ears and relaxed general posture

The performance component refers to that portion of the total body heat production resulting from the processes of producing milk, meat, eggs, or wool This component also includes the heat related to functions of reproduction and growth Performance is where the great-

external to the body's systems that tend to displace them from their resting or basic state, whereas, strain is the measure of internal displacement from the basic state brought about by stress Another way of describing strain would be to consider it as an estimate of the level of discomfort experienced by the animal Stress in the form of high temperature or humidity can be measured reasonably well, but it is virtually impossible to entirely characterize the "total strain" on the animal's system because of the constant shifts in function of various processes The best that can be done is to partially estimate the level of strain from body temperature, respiration rate, sweating, and changes in other processes Changes in productivity, growth, and reproduction rate can also be measured, although they too are only partial effects of the total strain on the animal

Figure 3 2 illustrates the trends in level of function of certain physiological processes brought about by either high or low temperature conditions The point where the vertical line (strain) and the horizontal line (stress) cross depicts the point of equilibrium of heat exchange between the animal and the environment Around this point of intersection is the "comfort zone"—the range within which small changes in atmospheric temperature produce no detectable increase or decrease in level of function and consequently, no discomfort that can be measured with confidence As already indicated, this range is about 13–18°C for most species of livestock

Although the concept of animal discomfort, as used in Figure 3 2, is useful in making practical husbandry decisions in tropical environments, it does not convey a clear picture of the sequence of events that the animal body goes through, why marked changes occur in one process and small changes in another, nor why repeatability is ordinarily low in the measures of strain, even under laboratory conditions where the level of stress is nearly constant. Adolph's (1964) terminology of "adaptagent" (the measurable force applied) and "adaptates" (the measurable changes produced by the animal) gives a clearer picture of what may take place when the animal is subjected to an environment outside its comfort range The basic adaptagent adaptate action is ΔA (the force) $\rightarrow \Delta E$ (the resulting response) If ΔE fails to compensate for ΔA, there is a shift in the heat balance But between ΔA and ΔE there may be a whole chain of events Adolph expresses this as

$$\Delta A \rightarrow \Delta B \rightarrow \Delta C \rightarrow \Delta D \rightarrow \Delta_{n} \qquad \rightarrow \Delta E$$

The compensations or attempted compensations by the animal to increased ambient temperature take place in approximately the fol-

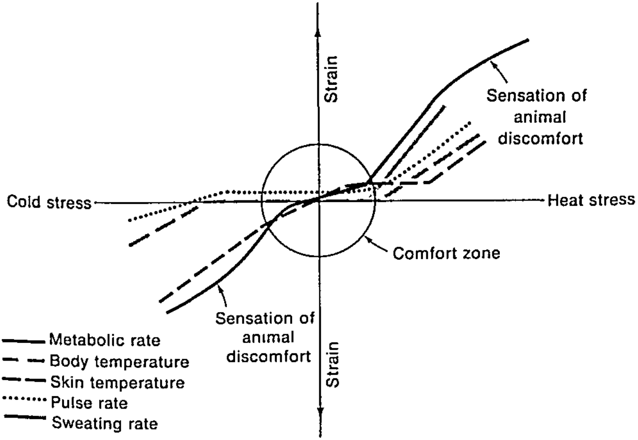

FIGURE 3.2
Stress-strain relationships with progressive changes from low to high temperatures. The "comfort zone" represents the portion of the temperature scale where no consistent change in physiological processes can usually be measured. As temperature is increased or decreased, the stress is reflected by greater strain on the animal.

lowing order: (1) changes in vascular blood flow, (2) initiation of sweating, (3) increased respiration rate, (4) changes in hormone secretions or endocrine activity, (5) changes in behavioral patterns, (6) increased water intake, (7) elevation of body temperature, (8) changes in the use of body water, and (9) change in state of hydration. If these steps fail to renew the animal's thermal equilibrium or shift it to a new plateau, progressive stages of failure of the heat regulation mechanisms will become evident.

Vascular Changes

The flow of heat from the central core of the body to the surface depends upon (1) direct conduction through the tissues, and (2) internal convection by the blood stream. The second process is responsible for the major part of heat transfer to the periphery, even when environmental temperature conditions are comfortable for the animal.

When the animal is put in a hot environment, the temperature differential between the skin and the core is reduced Although a higher skin temperature aids the flow of heat from the skin to the environment, it inhibits the flow of heat from the central core to the surface, thereby decreasing the rate of heat loss by conduction The animal compensates through vasodilation of the smallest arteries (arterioles) near the skin Increase in blood flow to the periphery takes place very readily, hence, it may be regarded as a universal reaction to warm environments While the dilation of vessels is principally due to the heat regulating centers, acting through nerve stimuli, it is no doubt assisted by the direct action of temperature on the skin and probably certain wavelengths of radiation if the animal is exposed to the sun The degree of dilation depends upon the level of stimuli and the location on the body

At high temperatures, blood flow through the human skin can be increased until heat is being transferred from the deep tissues at twice the rate for comfortable conditions Although few observations have been recorded for livestock, it seems reasonable to assume similar or near similar levels can be attained by them There is some indirect evidence for this assumption from experiments involving changes in cardiac output It has been shown that maximum blood pressure in cattle occurs when rectal temperature is 40 5°C, but maximum cardiac output occurs at 41 5°C (Johnson, 1967) Furthermore, during hyperthermia, the volume of blood in the heart and lungs increases, while pulmonary arterial pressure decreases

Sweating

If increased skin-blood flow is unable to restore the animal's heat balance in a hot environment, additional means of promoting heat loss are necessary Initially, there is likely to be some slight increase in insensible perspiration, or transudation of water through the skin, followed by the initiation of sweating (Bligh, 1967)

In many of the textbooks written before the mid-1950s, livestock other than horses are described as "low or non sweating" species More recently it has been shown that cutaneous evaporation of water is the major means of heat loss in cattle and sheep at high temperatures and also the most likely avenue of convective heat loss in swine and goats (Robertshaw, 1966) The earlier concept stemmed from the faulty assumption that the sweat glands of these species were apocrine rather than eccrine type and thus not under the control of the heat regulating centers

TABLE 3.2
Rate of evaporation (mg in 5 min from 10 cm²) from areas on the same cow under warm and hot conditions.

Hours from beginning exposure	26°C				38°C			
	Neck	*Withers*	*Paunch*	*Loin*	*Neck*	*Withers*	*Paunch*	*Loin*
2.0	7.0	25.8	15.4	5.8	29.7	55.7	36.2	31.0
2.3	8.3	20.1	9.0	4.8	30.2	51.9	30.5	27.2
3.0	5.2	26.7	13.2	5.9	28.2	54.3	24.9	31.3

Source: Adapted from McDowell *et al.*, 1954.

That evaporation from cattle, sheep, goats, buffaloes, horses, and donkeys is associated more with activity of the sweat glands than with transpiration through the skin is indicated by the following evidence: (1) the presence of sweat glands widely distributed over the surface of the various species (Nay and Hayman, 1956); (2) the lack of a regeneration-degeneration cycle in the sweat glands; (Findlay and Robertshaw, 1965); (3) the fact that the glands are not purely apocrine in type and show no nerve-endings; (4) the marked reduction of evaporation by treatments known to affect sweat glands (McDowell *et al.*, 1961); (5) the dramatic increase in the rate of evaporation with increased heat load, as illustrated in Table 3.2; (6) the response of glands to either hypothalamic heating or skin irritation; and (7) the appearance of wetness and even droplets on the skin of certain species.

The ambient temperature threshold for stimulation of sweating and the rate of output after stimulation vary among species. The ranking of domestic livestock for sweating is, in descending order: horses, donkeys, cattle, buffaloes, goats, sheep, and swine. Sweating in cattle is initiated at about 25°C (McDowell *et al.*, 1954). Above this temperature the sweat glands will make water available to the surface of the skin much more readily. A number of studies have shown that the sweat glands of cattle are adrenergic in nature. Similar evidence has been presented for goats. This means the glands are stimulated by nervous impulses sent to them through the sympathetic nervous system from the heat regulating centers. The response is a graduated one; that is, the number of glands acting at any one time may vary. In man, the rate of production by individual glands is adjustable, but it is not clear whether this holds for cattle and sheep. The current theory is that the glands of these species discharge completely upon being stimulated and must undergo a refilling stage after discharge. Nevertheless, the rate of output for a given area remains rather consistent (Table 3.2).

The sweat glands, stimulated by thermal stress, usually produce a film of water on the skin surface, which if evaporated rapidly restores body heat to near normal levels There are, of course, limitations to the process—e g , the extent of body surface in relation to mass, and the number of capillaries surrounding the glands Even human sweat glands, which perform much better than those of most other mammals, can seldom produce more than 2000 cm³/hr, and it is doubtful whether a rate of more than 600–800 cm³/hr can be kept up for other than a short time Experiments with cattle have shown that they can usually sustain a sweating rate of 200–300 cm³/hr Figure 3 3 illustrates the importance of evaporative cooling for cattle as ambient temperatures rise

It is often assumed that the wetness of the skin indicates the rate of sweat secretion But in fact wetness of the skin is determined by the rate at which the sweat is evaporating in relation to the rate of production In a humid environment with low air movement, a relatively low rate of sweat secretion may make the skin wet, whereas, in a dry climate with a relatively rapid rate of air movement, a high rate of sweat production may go unobserved Horses and donkeys often show visible moisture on the skin, but cattle show little except when the humidity is high, and sheep very seldom show visible moisture under any conditions

Contrary to a common concept, the rate of sweat secretion varies from area to area on the body (Figure 3 4) The rate of output for cattle at 40°C is 13 mg/5 min/10 cm² for the legs and ventral surface, 30 mg for the lower neck, and 37–40 mg for the main trunk The latter areas are nearest the major sources of heat production

The chemical composition of the sweat can be important to the animal The sweat of humans, horses, and donkeys, for example, contains significant amounts of sodium chloride (2–6 g/l) so salt must be replaced periodically Cattle sweat contains little salt, it consists principally of urea products low in mineral content Not much is known about the composition of sweat from sheep because of the sebum on the skin and wool But it seems that both cows and sheep have little need for salt replacement

Sweat gland density is also important Cattle have a sweat gland at the base of each hair follicle over the entire body surface The number per unit of body surface is influenced by age and body size, as well as breed There is evidence that Zebu cattle originating from the Indian subcontinent have 50–100% more glands per unit area than breeds originating in Europe The sweat glands of buffaloes have surfaces of 0 247 cm² each, which is about twice the size of those for cattle (0 124 cm²), but buffaloes have fewer glands so the glandular

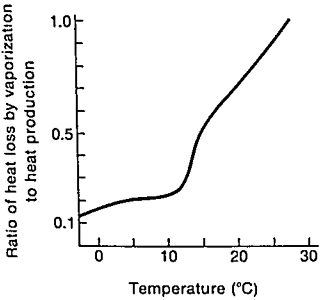

FIGURE 3.3
Importance of evaporative cooling for cattle in relation to total head production as air temperatures rise. (Adapted from Yeck and Kibler, 1956).

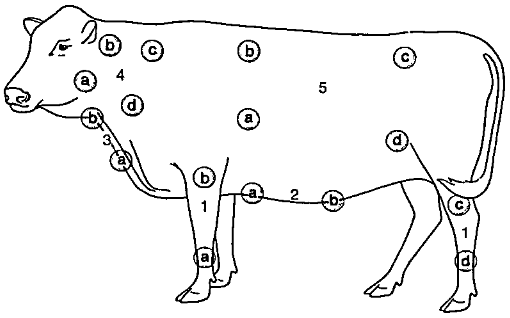

FIGURE 3.4
Locations and sublocations of body surface used in determining the distribution of surface evaporation from cattle. (1-legs, 2-ventral surface, 3-lower neck, 4-neck, and 5-trunk) (From McDowell *et al.*, 1961).

surface per cm^2 of skin surface is about 1.07 in buffaloes and 3.08 in cattle (Hafez, 1968).

Sheep have active glands at the base of each primary hair follicle but only rudimentary glands associated with the secondary follicles. The ratio of primary to secondary hair follicles varies between breeds, which means some breeds have more potentially active glands than others. The Australian Merino, for example, has a greater number of active glands than many of the British mutton breeds (Hafez, 1968).

In summary, sweating can play an important role in heat loss for

horses, cattle, water buffaloes, goats, and sheep, and a lesser role for swine The efficiency of function and total output of the glands can be increased by continuous exposure to hot conditions Rates of sweating vary among breeds of cattle and sheep, and variation among individuals in sweating capability is also quite large A more extensive discussion of rate and control of sweating in livestock is given by Yeates (1965)

Respiration

In domestic livestock increased respiratory activity is an important means of increasing heat loss at high temperatures It is usually the first visible sign of response to heat stress, but it has been placed third in the sequence of adaptates because the unnoticed processes of vasodilation and sweating usually occur earlier The greater the volume of air that can be breathed in, warmed, and humidified, the greater the resultant heat loss In cattle, sheep, goats, swine, and buffaloes increased respiration rate is regarded as one of the primary mechanisms of heat balance The rate increases with increasing air temperature, the most pronounced rise occurring above 29°C In studies conducted under controlled temperature conditions, the humidity of the atmosphere seems to have about the same effect on respiration rate as air temperature (McDowell, 1967), but under field conditions humidity seems to have only a minor influence Johnston and Stone, 1966

At 18–20°C a cow will usually have a respiratory rate of about 20 breaths per minute and a volume of expired air of 40–60 liters, depending on body size and breed An expired volume of 60 l/min will provide 1 7 kcal/min loss of heat. At 40°C, the same cow may breath 115 times per minute with an expired volume of 300 liters This rate of air exchange will increase the rate of heat loss to about 5 6 kcal/min

The amount of water vaporized from the respiratory tract of cattle increases with rising temperature (Table 3 3), however, it does not rise as rapidly as the rate of water loss from the body surface The data in Table 3 3 point to the fact that respiratory vaporization is rather important in the range of 10–27°C but of lesser significance in total vaporization at high temperatures Its proportionate contribution to heat regulation declines markedly above 30°C

A high respiration rate can be an efficient means of increasing heat loss for short periods (Bianca, 1965), but if high rates continue for several hours or longer, serious problems are likely to arise for the animal Continued high respiration rates may interfere with feed-

TABLE 3.3
Respiratory and surface evaporation rates (gm/m²/hr) at various air temperatures for dry mature Zebus and Holsteins.

Air Temp. (°C)	*Respiratory*		*Body surface*		*% total by respiration*[a]	
	Zebu	*Holstein*	*Zebu*	*Holstein*	*Zebu*	*Holstein*
10	12	27	52	40	23	40
21	15	30	70	124	29	42
27	14	41	84	143	27	36
32	14	45	154	133	16	23
35	22	49	156	136	17	25

Source: Kibler and Brody, 1950, 1954, McDowell and Weldy, 1967
[a]Percent total vaporization loss through the respiratory tract

ing and rumination, add to body heat production from muscular activity, use energy that could be utilized for other purposes, and lead to a reduction in the CO_2 combining capacity of the blood plasma because of hyperventilation. The first three conditions begin to occur when temperature conditions exceed the optimum by 3–5°C. As environmental temperatures rise, their influence on the animal's thermoequilibrium increases. Hyperventilation to the point that the alveolar pCO_2 is below that necessary for the normal rate of diffusion of CO_2 from the alveoli, a condition termed "respiratory alkalosis", does not generally occur in livestock except at extreme temperatures—i.e., 35°C or above. However, there is one exception: hyperventilation may become serious at less extreme temperatures if the tidal volume remains high after respiration has increased 100% or more. (Tidal volume refers to volume of air per breath.)

Cattle exposed to thermal stress generally show one of two types of breathing: "deep bellows" or "shallow panting." The same is sometimes observed in sheep. The differences in depth can be observed by watching the extent of the movement of the flanks as the air is inspired. The bellows breather has a high tidal volume—up to 3 liters or more for the cow. If the bellows breathing persists in a high respiratory rate (80 breaths per minute or higher) and a high tidal volume (>2.8 liters) hyperventilation may lead to respiratory alkalosis, which in turn may drastically upset the animal's other physiological processes.

If the animal adopts a pattern of rapid shallow breathing, or light panting, it will have a lower tidal volume but about the same or even a higher rate of air exchange than the "bellows breather." Because of the lower tidal volumes the shallow breather runs much less risk

FIGURE 3.5
An animal under thermal stress using "open mouth" breathing and drivelling. This is undesirable as the water loss by drivelling removes very little heat from the body. (Courtesy J. C. Bonsma, University Pretoria)

from over ventilation. Rapid shallow breathing has the added advantage of passing the largest volume of air most rapidly over the nasal membranes, where the greatest amount of water is available for evaporation.

Another type of breathing often observed in cattle, sheep, and swine under thermal stress is "open-mouth" breathing, in which copious salivation is evident (Figure 3.5). This means of water loss is very inefficient in promoting heat dissipation. The amount of salivation varies quite widely and is largely dependent upon the type of breathing. "Open-mouth" breathers often show the poorest tolerance to heat.

High respiratory rates in cattle or sheep do not necessarily indicate that the animals are successfully maintaining their thermal balance; rather, they show that the animals are already overheated and trying to restore normal balance. Therefore, in the absence of other

evidence, a low respiratory rate under hot conditions usually identifies the animals with lesser discomfort. Quick, short bursts of respiration can be useful in aiding the body until other means of heat loss can be activated. But rapid breathing in livestock is more likely to become persistent. As will be shown later, some of the inefficiencies of persistent high respiration rates are factors to consider in developing animal husbandry practices and to an extent in selecting the most suitable breeds for hot climates.

Endocrine Functions

At present, the changes in the functioning of the endocrine glands as a result of hyperthermia are the least understood. It has been demonstrated a number of times that high ambient temperatures bring about a decreased functioning of the thyroid gland, which acts either directly or indirectly to reduce appetite. Whether the appetite center in the hypothalamus acts directly on the thyroid gland to decrease its activity after being warmed by the circulating blood or the thyroid gland initiates a feedback that tells the appetite center to decrease the desire for feeding is unknown. Whatever the process, the thyroid gland has an important influence on animal growth rate and performance in hot environments—either directly, through its role in appetite, or indirectly, through its role in heat production.

Air temperature above 30°C seems to have a marked influence on the adrenals as evidenced by a marked reduction in blood hydroxysteroids. The excretion of both 17-hydroxysteroids and 17-ketosteroids is reduced. This in turn affects metabolism (Robinson and Morris, 1960).

There is limited evidence that high temperature conditions may have some effect on the anterior lobe of the pituitary, causing a decrease in prolactin secretion, which is important to the lactating animal (Nat'l Acad. Sci., 1971).

High temperatures may also decrease the output of gonadotrophin by the anterior lobe, leading to inadequate estrogen or progesterone production and consequently to poor reproductive performance. The posterior lobe of the pituitary affects heat balance significantly through the shifting of electrolytes during mobilization of water for evaporation from the body.

Low feed intake has an effect similar to that of high temperatures on the functioning of the endocrine glands; but the fact that level of functioning increases at low temperatures without appetite being

involved suggests that thermal stress does have a direct influence on endocrine activity

Behavior

In a broad sense, all modifications of physiological processes to regulate heat exchange could be classed as modification of behavior In this discussion, behavior refers to shifts in the usual patterns of posture, movement, and food intake that may take place under thermal stress These alterations are made by the animal either to reduce heat production, to promote heat loss, to avoid adding heat The reluctance of females to mount one another during estrus, the decrease in the consumption of roughages in proportion to concentrates, and the inclination to seek shade are some examples Changes in behavior to promote heat loss are ordinarily directed toward increasing conduction or conserving body water

The mechanisms responsible for changes in behavior patterns are not known There is probably some association with the so-called "sleep centers" in the hypothalamus, but there may also be some involvement of the "higher" portions of the brain

Like men, livestock tend to adopt a relaxed posture and to minimize exertion in hot environments Ruminants, for example, cease to graze and swine seek a cool surface to lie on or water to submerge in The usual impression that heat loss by conduction-convection is enhanced when an animal is lying down only holds if the surface in contact is considerably cooler than the body Even so, a significant rate of exchange would occur for only a limited time And in the meantime, the animal is removing about one third of its surface from contact with the air

Some of the most striking examples of changes of behavior under hot conditions are described by Schmidt-Nielsen (1964) He shows that many animals, such as the kangaroo rat, manage to survive under extreme temperatures and with little or no water by changing their patterns of behavior, largely becoming "escapists" The kangaroo rat avoids exposure to the high temperature by burrowing into the ground Others, like the jack rabbit, hide in small depressions or seek shade to prevent the body from taking on excessive heat and to prevent excessive water loss

Although there is little factual evidence regarding the extent of changes in behavior under thermal stress, it is clear that alterations in posture, activity, eating habits, and other behaviors are important adaptates for reducing the effect of heat stress

Water Intake

When the heat load causes the animal to initiate steps to increase rate of evaporation from the body, the water initially comes from the blood. This must be replenished by water mobilized from a number of sources. Among these are the stomach, intestine, interstitial fluids, feces (see Table 3.1, fecal water), and probably oxidation of some stored carbohydrate, fat, or protein. As water is drawn from these sources, some action through the blood, or more likely through nerve impulses, acts on the "thirst center" in the brain to create a desire for restoration of the body water to normal levels. Just what the extent of dehydration must be before the thirst center becomes operative has not been discerned, but it has been demonstrated that man and the majority of domestic animals will make efforts to seek water when the equivalent of less than 1% of the body weight has been lost (Adolph, 1964).

As ambient temperature rises, there is a corresponding increase in free water intake. A 500 kg lactating cow will ingest approximately 50 kg of water per day at 21°C, but may increase this by 25–100% at 32°C (Table 3.1 and 14.3). Some individual cows or sheep will increase their intake by 100% or more at 30–33°C, but intake generally reaches a ceiling when ambient temperatures exceed 35°C (Johnson, 1967). Water needs for livestock are discussed further in Chapter 14.

Body Temperature

Excessive heat in the body produces undesirable effects on a number of physiological processes, principally metabolism, by lowering of the feed substrate to the cells and lowering of the calorigenic hormone levels (thyroid stimulating hormone, ACTH, and hydroxysteroids). Exposure to 27°C or above for several hours will frequently cause enough buildup of heat in the body to make the body temperature rise. A rise in body temperature is often taken as a sign that the animal has failed to develop or bring into action the proper adaptates to maintain heat balance. Although there may be disadvantages, a rise in temperature can afford advantages. According to Schmidt-Nielsen (1964), the camel uses an elevated body temperature very effectively. Under hot desert conditions the camel may allow its body temperature to rise 4–6°C during the day in order to promote or maintain an appreciable level of heat loss by conduction. This reduces the need for surface evaporation, which in turn conserves body water.

Although a rise in body temperature of 0.5°C or higher often results in a depression of feed intake, increased respiration rate, and a decrease in performance, it may be that cattle, sheep, or swine tend to let body temperature rise in order to aid heat loss by conduction since they do not have a sweating mechanism as efficient as man. The extent that body temperature may be allowed to rise or the extent that a rise in temperature is needed to activate the physiological processes involved in promoting heat loss is unknown. In any case, the negative correlation between level of body temperature and milk yield implies that some elevation of body temperature may be acceptable.

Use of Water

Within the 13–18°C range the major avenues of water loss from the body are through feces, urine, respiration, and evaporation from the skin surface, in that order. Under high temperature conditions (27°C or above) the order of the magnitude of water loss is essentially reversed, and some water is lost through drivelling of saliva (Table 3.4). The reverse order is also the order of the efficiency of removal of heat from the body. A small number of animals (about 1 per 15 cattle and 1 per 5 sheep) increase urine output as a means of promoting heat loss instead of increasing the output by surface evaporation. This condition, characterized by high intake of water and high output of urine, is called "diuresis." Diuresis is undesirable both because it is inferior to increased sweating as a method of heat removal and because the animal with extremely high water intake generally has an above-average loss in appetite. Sheep have been known to die under thermal stress when they have devoted almost their full time and attention to taking in water. Therefore, the way the individual animal shifts its avenues of expelling water from the body can be important in efficiency of promoting heat loss.

TABLE 3.4
Water loss (kg/24 hr) by nonlactating Holstein cows at 20° vs 30°C

Source of loss	*20°C*	*30°C*
Feces	13.0	9.8
Urine	11.7	14.7
Saliva	0.0	2.4
Respiratory tract	7.6	11.7
Body surface	10.6	29.3

Source: Adapted from McDowell and Weldy 1967.

State of Hydration

Failure to maintain the water content of the body at a normal or near normal level (dehydration) will affect primarily blood volume and, the circulatory volume to capacity ratio. Dehydration militates against a high rate of sweating as well as many other body functions. It is not surprising, then, that animals' responses to hot environments become worse when adequate water intake is not permitted. Apart from the initial slight dehydration voluntarily adopted oftentimes by animals dwelling in warm climates, it can be taken as a general principle that tolerance to heat stress, as well as the efficiency of other body functions, is reduced as dehydration advances. Dehydration, which is simply a failure to maintain the normal water content of body fluids, can be brought about by many conditions other than a lack of drinking water, such as diarrhea.

Water is normally passed from the stomach into the intestines rather rapidly, with about 80% being absorbed into the bloodstream from 20 to 30 minutes after it is ingested. If water is readily available and the level of thermal stress not extreme, most animals are able to prevent dehydration from reaching the stage where body functions are impaired.

Failure of Heat Regulation

Unless the animal is able to restore its heat balance by means of the adaptates mentioned, "progressive degeneration" occurs—expressed in the order of diarrhea, failure of the heat regulation centers, weakness, staggers, convulsions, and death. Failure of the heat regulating centers in cattle first appears as an unsteady stance or a staggering gate followed by paralysis in the rear legs, with eventual death from kidney failure. Postmortem examinations reveal that the muscles in the rear legs become dystrophic, due to loss of nerve function brought about by damage either to the cells in the central nervous center or destruction of some of the local centers. Such degeneration from the direct influences of thermal stress seldom occurs, as animals take evasive steps by changes in behavior or make drastic reductions in heat production.

Another condition that often influences the animal's rate of heat exchange is its state of health. Since most systems of the body become involved in some way in the course of heat regulation, almost any disturbance of a body function is likely to have some effect upon the

efficiency of heat regulation Similarly, the significance of almost any disease or disturbance of bodily function may be affected by demands upon the body for heat regulation Many infections, for instance, are accompanied by a rise in body temperature This comes about due to a change in the "setting" of the heat regulating centers resulting from the infection In other words, heat loss is inhibited until the temperature rises to a new level Under these circumstances, the normal avenues of heat loss are upset

Many skin conditions, such as wool rot in sheep and sunburned white skin in cattle or swine, will interfere with the proper functioning of the sweat glands and are likely, therefore, to interfere with adjustment to hot environments

THE ROLE OF ANATOMICAL CHARACTERISTICS IN HEAT EXCHANGE

There are certain external body characteristics that can afford advantages to an animal in withstanding the stress imposed by a hot climate These include skin, surface area, pelage, appendages, fat storage, and muscling near the skin

Skin

The extent of pigmentation and thickness of the skin are related to rate of heat exchange Thickness which varies on different parts of the body, is influenced by both age and nutrition (Older animals and poorly fed animals have thicker skin) There is also evidence of differences among breeds of cattle (Table 3 5) There seem to be two extremes one associated with cold climates (South Devon) and the other associated with hot, dry climates (Africander) In the cooler climates, thickness varies with season, increasing in winter as a means of reducing heat loss In hot, dry climates a thicker skin, such as that of the Africander, helps to reduce the effects of thermal radiation and reduce water loss In warm, humid climates a thin skin would be desirable for opposite reasons The importance of pigmentation, which determines color of skin, was discussed in relation to solar radiation (Chapter 2)

TABLE 3.5
Average thickness of skin reported for several breeds of cattle and buffaloes.

Breed group	*Location*	*Thickness (mm)*
Africander	South Africa	8.73
South Devon	United Kingdom	8.15
Hereford	United States	6.70
Buffalo	Egypt	6.50
Zebu cross	United States	6.43
Illawarra Shorthorn	Australia	6.23
Nguni	United States	6.00
Boran	Uganda	5.98
Zebu	India and United States	5.77
Angus	United States	5.57
Shorthorn	United Kingdom	5.69
Jersey	United States	5.46
Angoni	South Africa	5.46

Surface Area

When ambient temperature is below body temperature, a large body surface affords obvious advantages in heat loss by conduction, but when the ambient temperature is near or above body temperature, a large surface in relation to mass has disadvantages. A large body surface is helpful too under hot, humid conditions as it aids in promoting surface evaporation. There are breed differences in surface area per unit of body mass and body configuration that are worthy of consideration in determining the type of animals most adaptable to hot climates. These points are covered in Chapter 5.

Pelage

The length of hair coat of livestock is dependent upon species and breed, nutritional level, temperature conditions and prevailing photoperiod. Animals indigenous to warm climates, especially cattle, tend to have characteristically short hair coats. Since rate of surface evaporation is related inversely to length of hair, where rapid evaporation is desirable for convection-evaporation, short hair is preferable.

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TABLE 3 6
Hair follicle density length and diameter reported for several groups of cattle and buffaloes

Breed	Approximate no /cm²	Follicle Length (mm)	Follicle Diameter (μ)
Buffalo (Egypt)	394	–	–
Zebu (India)	1400 to 2600	3 6	54 2
Jersey (U S)	600 to 1100	5 1	56 1
Holstein (U S)	550 to 1095	4 9	55 7

Tolerance to heat stress has been shown to increase after clipping of the hair coat (Yeates, 1965) When necessary, cattle will shed their long hair coat, leaving a shorter one, as an adaptive mechanism to promote heat loss The lay of the hair (erect or lying flat) is another important factor in convective cooling and to some extent in reducing thermal radiation (Turner and Schleger, 1960)

Since it has been found that cattle have a sweat gland at the base of each hair follicle, the number of follicles per unit area will have a relationship to the potential effectiveness of heat loss by sweating Table 3 6 gives some ranges of hair follicle density for groups of cattle and buffaloes The ranges for cattle are large, types originating in the tropics (Zebu) having about twice the hair density of those from the temperate areas (Jersey and Holstein) Follicle diameter is about the same for all the cattle breeds (Hafez, 1968)

The oiliness of the hair is also significant. Secretions from the sebaceous glands of the skin are responsible for oiliness Oily hair absorbs less radiation than dry hair and also tends to retard evaporation from the skin Consequently, wool is an advantageous covering in a hot, dry climate, but not in a humid one

Hairy animals indigenous to hot climates are generally lighter in color than those indigenous to the temperate zones This may be partially inherited and partially an adjustment to the climate Studies conducted over 12 month periods in climate controlled laboratories at 27°C showed that the hair coat of cattle tended to get lighter in color with progressive exposure to the hot conditions (Ragsdale *et al* , 1957)

In a hot climate white or light colored hair affords some advantage in reflecting thermal radiation, and thus reducing the uptake of heat

by the body. But there is no evidence that color constitutes a significant role in heat loss.

Appendages

Many people hold the view that the Zebus are superior to European breeds of cattle in thermoregulatory ability largely because of their large ears, dewlap (hanging fold under the neck), navel folds, and prepuces. But it has been found that the dewlap has a low surface evaporation rate at high temperatures as compared to other areas of the body—the dewlap secretion rate is 30% below that of the forechest, paunch, or neck (McDowell *et al.*, 1961). That the dewlap is likely to produce less moisture for evaporation is substantiated by comparison of the inner-skin-surface blood vessels of the dewlap and the upper neck (Figure 3.6). In the top portion of the figure is a section of skin from the neck of a Zebu cow about 15 cm above the dewlap. The right section of the photo depicts the center of the fold of the dewlap. (This area corresponds to 3a in Figure 3.4). In the neck section the veins are larger and more numerous than in the dewlap.

The ears of the Zebu are larger than those of European breeds of cattle and very vascular; but their surface in relation to total body area is small (<2%), making them of questionable significance in the overall heat loss capability. Unlike the jackrabbit's ears, which are very large relative to its body and tend to remain unfurled, the Zebu's ears curl over with increased size. The tendency to fold over, of course, reduces its efficiency for heat loss by conduction.

Zebu females normally have a larger vulva than European breeds. This area is highly vascular, and it has been suggested that the size of the vulva is related to the overall capability for promoting heat loss. But the vulva represents a small portion of the body surface, it is consistently covered by the tail, and it is some distance from the major sources of heat production in the body.

The hump of the Zebu contains sweat glands larger than other areas of the body; but again its location in relation to the major centers of heat production is such that its contribution to the total capability for evaporative cooling is limited. It is also held by many that the fat tail or fatty rump of some breeds of sheep and the exceptionally large horns of some breeds of cattle indigenous to Central Africa and water buffaloes are important in promoting heat loss but there is little proof. In brief, the appendages play a role in heat dissipation but experi-

FIGURE 36
Sections of inner skin surface from the neck 15 cm above the dewlap (top) and center of the fold of the dewlap (bottom) of a Zebu cow illustrate the contrast in number and size of the veins serving these areas.

mental evidence does not bear out the commonly expressed view that appendages are the key factor for adaptation to hot climates.

Fat Storage

When fat is stored next to the skin, it impairs heat loss. Thus the storage of fat in the hump of African Zebu cattle and camels, or in the tails or rumps of many groups of sheep native to the Middle East and Africa, may afford an advantage in promoting heat loss in comparison to an equal amount of fat stored immediately adjacent to the skin. Contrary to common belief, the hump of the Indian Zebu and the Zebu cattle found in the western hemisphere do not have large reservoirs of fat storage. In these cattle the fat content of the hump is closely related to the general fat covering of the body. Although the hump of these cattle may be well marbled with fat, if the animal has good general fleshing, most of the fat is stored immediately adjacent the skin.

Muscling Near the Skin

The funicular muscles attached to the skin are thought to be important in promoting heat loss but their role is unknown. Probably the most important benefit of well developed funicular muscles is in repelling biting insects. Ability to move the skin on parts of the main trunk readily make it more difficult for ticks, mosquitos or other insects, to implant on the surface. Bonsma (1949) found, for example, that Africander cattle of South Africa had 15 ticks per unit area as compared to 175–275 on European breeds. He attributed the difference to the better developed funicular muscles of the Africander cattle.

Differences in external body characteristics, particularly configuration, can sometimes be helpful to the animal in a hot environment. But research has shown that the differences among breed groups for these traits are not the principle factors responsible for adaptability to adverse climates.

ACCLIMATIZATION

Repeated or continuous exposure to a hot environment develops not only adaptive functioning of the animal's main physiological processes, but also functional or structural changes that increase its ability to live in this type of environment The animal that has shifted its processes to a new plateau to the extent it shows a minimum rise in body temperature is considered more nearly acclimated or fit for living in a hot environment than one that shows a major shift in the heat balance However, this concept is far too rigid because immediately upon exposure of an animal to a hot environment, heat regulation and acclimatization merge imperceptibly At any given time, the temperature of the body depends not only on the heat load at that time but also to some extent on the preceding heat load (Prosser, 1969) This makes it obvious that regulation of heat balance and acclimatization are continuous and interdependent no matter what the external environment may be

We need, therefore, to distinguish between the state of acclimatization and the ability to acclimatize It is reasonable to assume that animals that remain for long periods at a fairly constant temperature, for example, at low altitudes near the Equator, are less able to adjust to a new environment than animals that are accustomed to changes of climate The state of acclimatization to hot conditions may be good among animals indigenous to the area, but their ability to adjust to another environment is likely to be poor There is some experimental evidence to suggest that fluctuations of temperature with different seasons improve the ability to acclimatize This raises the question, is it possible for an animal to be acclimatized to both heat and cold at the same time? Insofar as acclimatization is brought about by the hypothalamic centers, it is possible for a variety of conditioned reflexes or habituations to exist simultaneously Thus it appears that acclimatization can be used to describe a fluctuating condition taking place within the body If this is true, then attempts should not be made to rigidly describe either the state of acclimatization of an animal or its capability to acclimatize to changes in environment

All animals have certain capabilities of adjusting to unfavorable environments These vary to some extent with species The age at which the animal is exposed to a new environment is apparently quite important in the limitations of its adjustments Experiments with mice reared at 21°C and 32°C have shown that those reared at the high temperature developed long, large tails, provided exposure began at birth or shortly thereafter If the 21°C reared mice were shifted to the high temperature as adults there was little change in the size

of the tail. Also, if mice coming from litters born in the 32°C temperature were switched to the cool temperature they failed to develop the enlarged tails. This clearly shows an adaptate-environment interaction (Harrison, 1963). Such pronounced changes in phenotypic traits have not been observed in large animals, but the age at which cattle or other stock are moved from a temperate climate to a hot climate is important in their ability to adjust to the hot environment.

The methods of measuring the adjustments or lack of adjustments are also important in assaying how the animal functions in a new environment. For instance, short-term exposures of cattle to high temperature conditions in a controlled temperature laboratory have resulted in a high rise in body temperature in some animals, and a relatively small change in others. The difference in magnitude of response between animals or groups in these experiments has been used to predict suitability for a hot climate. But it is evident from the discussion of the basic phenomena of heat regulation and the employment of adaptates that decisions based on one measure may not reflect the real suitability of an animal to a hot environment. It is conceivable that the animal with the more elevated temperature will be functioning less efficiently than when its temperature was lower, but as often happens with lactating cows, the higher producer has the higher body temperature under hot conditions. So functional adaptation would be a more satisfactory measure of acclimatization from the livestock producer's standpoint. (See Chapter 5.)

The thyroid gland is clearly involved in acclimatization, and it has been suggested that acclimatization can be characterized by restoration of thyroid activity to normal levels. The hypothalamus is also closely involved, both directly, through determining which heat loss functions are put into stronger action, and indirectly, through the action of the thyroid gland. Metabolic level and duration of exposure are both basic factors in assaying the degree of acclimatization.

In a complex, closely integrated mechanism such as the animal body, it is inevitable that an alteration in activity of one part should have repercussions in other parts. Unfortunately, these interrelationships among various body functions are by no means clear at this time. (See Chapter 5.)

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4

Consequences of Thermal Stress on Livestock Performance

The preceding chapter dealt with the influences of warm climates on the basic processes of heat exchange between the animal and its surroundings. This chapter is concerned with the direct consequences of thermal stress on those processes related directly to animal performance. The indirect effects of warm climates—through feed supplies, diseases, and parasites—will be taken up in later chapters.

There is a mass of technical literature verifying the hazards for livestock of temperature conditions above and below their "comfort zones." But most of the studies have been conducted under laboratory, rather than field, conditions. So at present our conclusions about the direct impact of warm environments on livestock performance are not supported by as much research as we would like. Nevertheless, a fairly clear picture has emerged from research and experience in the field, to a point that a degree of rationale can be made about variations among species and breeds in their responses to thermal stress.

FEED INTAKE

One of the first noticeable responses of most livestock to thermal stress is a decrease in food intake The extent of the depression appears to be directly related to the level of stress (Size and age of the animal are also factors) This relationship is illustrated with data from swine feeding in Figure 4 1 Similar observations have been made with laying hens Birds decrease their intake about 1 5% for each 1°C rise in environmental temperature above 25°C Lactating cows, producing 30 kg or more of milk per day, exhibit some depression in appetite at 25°C, show a marked decline above 30°C, and virtually stop eating at 40°C (Johnson, 1967)

In one series of experiments, the digestible energy consumed by lactating Holstein cows declined 11% from the level at 21°C after one week of exposure to 32°C There was a further decline of 1% the second week (Table 4 1) The level of feeding prior to the time of thermal stress is a factor in determining both the ambient temperature at which appetite will decline and the rate of decline (High fed animals show more decline under stress than low fed ones) The type of feed offered is also important If lactating cows are given a ration of hay and

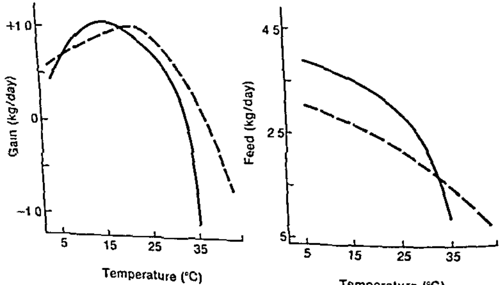

FIGURE 4 1
Feed consumption and rate of gain of pigs at different temperature conditions Solid and dashed lines indicate heavy and lightweight pigs (Adapted from Heitman and Hughes, 1949 "The effects of high temperature and relative humidity on the physiological well being of swine " J Animal Sci Fig 1, Vol 8 pp 171–181 1949 Copyright by the American Association for the Advancement of Science, 1967, Pub 86)

TABLE 4.1
Efficiency of energy utilization for milk yield, and digestibility for lactating Holstein cows at 21°C and after 7 and 14 days of continuous exposure to 32°C temperature.

Factor	Avg for 12 cows at 21°C	Avg % deviation from 21°C level	
		7 days at 32°	14 days at 32°
Efficiency of utilization of digestible energy for milk (%)	60	−35	−51
Digestible energy (DE) consumed (Mcal/day)	38	−14	−18
Maintenance requirements (Mcal/day)	15	−1	−2
Mcal DE for production/day	22	28	34
Solids corrected milk (Mcal/day)	12.6	−28.6	−39.7
Digestibility			
Dry matter (%)	60	3	5
Calories (%)	59	1	2
Fiber (%)	35	7	12
Rate of passage		0	0

Source: Adapted from McDowell *et al.*, 1969.

silage on a free choice basis, plus concentrates at the rate of 1 unit to 3 units of milk produced, they will first reduce the intake of hay ($r = -0.67$ for hay intake when maximum daily temperature is above 28°C). Silage consumption will decline when maximum daily temperature exceeds 31°C, but full intake of concentrates will normally continue until maximum daily temperature exceeds 35°C.

The tendency of animals to reduce their consumption of hay under thermal stress was demonstrated in another experiment in which 8 pairs of identical twin Jersey heifers were separated and reared either in New Zealand or the humid tropical climate of Fiji. They received the same type of hay and concentrates in both places. The Fiji group ate less hay but more concentrates. Consequently, the total starch equivalent intake was nearly the same in the two environments (Payne and Hancock, 1957).

In general, young cattle have a higher threshold to high temperatures for decreased appetite than lactating cows, although this point is not clearly established. In two series of experiments with groups of 12- to 18-month-old Shorthorn heifers exposed to 32°C en-

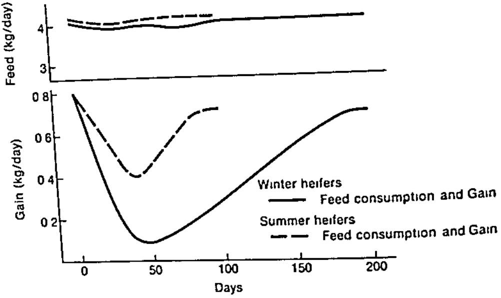

FIGURE 4 2
Rate of feed intake and average daily gains for groups of heifers preconditioned to cool (winter) and warm conditions (summer) before and during exposure to a constant temperature of 32°C for 95 or 200 days (Adapted from McDowell 1968)

vironments continuously for either 95 or 200 days, feed intake declined only 3–5% (Figure 4 2), and returned to normal levels after 2 weeks On the other hand, a series of experiments with groups of 3-month old Shorthorn heifers raised for 9 months at either 10 or 27°C showed that feed consumption (measured on an actual intake basis) was continuously lower at 27°C (Ragsdale *et al*, 1957) But the heifers kept at 27°C were smaller at the beginning and remained so for the 9 month period When the intake of the two groups was expressed as intake per unit of metabolic size ($W^{3/4}$), the influence of temperature on intake was small

Numerous research reports have stressed the differences among breeds of cattle in their changes in feed consumption with rising environmental temperature—particularly between Zebu (*Bos indicus*) breeds and European breeds Two prominent series of experiments were performed under controlled temperatures at the University of Missouri (Ragsdale *et al*, 1950 and 1951) It was reported that the feed intake of lactating Jersey, Brown Swiss, and Holstein cows was depressed at 27°C, while that of Brahman cows did not decline until 38°C At 20°C the three European breeds consumed three times as much feed and produced five times as much milk as the Brahman At 35°C the European breeds averaged almost three times more milk than the Brahman and their feed consumption remained higher Even

under the most severe temperature (41°C), the Jerseys, Brown Swiss, and Holsteins averaged 43% higher feed intake and 45% higher milk yield than the Brahman, although the average feed intake and milk yields of the European breeds was markedly lower than at 20°C. At the University of Missouri studies of the influence of 27°C on the feed intake of Brahman, Santa Gertrudis, Brown Swiss, Holstein and Jersey heifers were also conclusive on the importance of differences among breeds. In another test in Australia (Allen *et al.*, 1963), Jersey heifers were reported to have a greater depression of feed intake in a hot room at 39°C than Zebu heifers. Under cool conditions the Jerseys consumed approximately 50% more feed than the Zebus. And even though the feed intake of the Jerseys declined about 40% at 39°C, their level of intake was similar to that of the Zebus.

Under field conditions, it has been reported on numerous occasions that Zebu cattle continue to graze during the hotter part of the day while European breeds seek shade. It has been assumed that this pattern of behavior reflects higher intakes by the Zebus. But there is little evidence that the Zebus make greater gains or produce more milk than their herdmates of pure European breeds, or crosses of European and Zebu breeds. Experiments in Africa have shown markedly higher levels of intake by Herefords than indigenous Zebus (Rogerson *et al.*, 1968). It seems, therefore, that more concern has been expressed over breed differences than is warranted by current research.

It is evident that reduced intake of feed is a response to heat stress that lowers performance in the warm climate regions. The questions are: what makes the animal tend to stop eating sooner at higher temperatures? and what remedial measures can be employed? Even though the direct and indirect pathways for controlling changes in appetite are not entirely defined, there are no doubt at least three factors involved: (1) direct regulation by the heat regulating centers, (2) interference with feeding by high respiration rate, and (3) changes in behavior directed toward decreased heat production or removal of the animal from the proximity of feeding areas, such as seeking shade.

Brobeck has suggested, from studies with rats, that the heat produced due to the specific dynamic effect of feed, causes the rostral cooling center of the hypothalamus to stimulate the medial satiety center and to inhibit the lateral appetite center, causing feed intake to cease. An external heat load adds to the heat produced from digestion, resulting in a more rapid cessation of feeding (Brobeck, 1960). The observation that the adrenal cortex is required for the maintenance of appetite is important because it seems that adrenal cortical

activity is reduced by heat Brobeck also holds the view that gastric distention and blood glucose or amino acid level probably interact with the other hypothalamic events to produce a final pattern of feed intake

There is some further evidence from experiments with rats that metabolites circulating through the hypothalamic region may determine food intake Changes of hypothalamic temperature in ruminants have also given results that support the thermostatic hypothesis Cooling the anterior hypothalamus and preoptic areas caused a satiated goat to eat, while warming these areas inhibited eating in a fasted goat (Anderson and Larson, 1961) Still, others have concluded from studies with goats that hypothalamic temperature is more related to activity than food consumption per se This theory is based on the observation that goats are more active when eating than when standing quietly or resting

Though there is some evidence that thermostatic regulation plays an important role in regulating feed intake, it is difficult to formulate a hypothesis for purely thermostatic regulation of voluntary intake under hot conditions because in ruminants the peak of heat production frequently occurs after food intake has voluntarily ceased Since the concentrations of ruminal acetate, propionate, and total volatile fatty acids do not increase significantly following feeding, a theory based on chemostatic regulation is equally difficult to formulate The peaks in the concentrations of volatile fatty acids in the rumen and blood are, more frequently than not, attained after food intake has ceased

The evidence from experiments conducted under constant temperature conditions in laboratories and in some cases field experiments suggest that the prevailing temperatures in much of the N-S 30° latitudes have a direct effect on appetite and level of feed intake But apparently the direct influence of temperature does not seriously impair intake under good management regimes Cattle and sheep may seek shade during the hottest part of the day and avoid eating, but if adequate feed is available they will normally consume their full requirements in the cooler part of the day Isolating animals from feed after mid or late afternoon and during the hours of darkness is thus a mistake, because it restricts total daily feed consumption Dry lot feeding experiments in Georgia and Louisiana showed that during the summer months lactating cows shifted their customary pattern of consuming most of their roughage (about 65%) during the daylight hours to around 60% during late afternoon and evening and approximately 20% from daylight until 10 00 A M This shift in feeding pat

tern did not materially depress the level of milk yield. Management practices designed to insure maximum intakes of feed are discussed further in Chapter 14.

EFFICIENCY OF FEED UTILIZATION

Most of the reports dealing with feed utilization in relation to temperature levels are expressed as gross efficiency—i.e., the amount of feed consumed per unit of yield measured as milk or body weight gain. The research has generally shown depression in gross efficiency, decreased intake of feed, and lowering of total heat production with rising temperatures, up to about 30°C. However, above 30°C there is a rise in heat production because of the added heat from increased activation of the heat loss mechanisms (Figure 4.3). With the lowered intake and resulting lowered total heat production, a greater proportion of the energy consumed goes for maintenance, resulting in a decline in gross efficiency.

Table 4.2 compares the effects of cool (10°C) and hot conditions (32°C) on the gross efficiency of swine of various weights. These comparisons suggest that gross efficiency (feed/100 kg gain) is related to both temperature and the size of the animal. In the small pigs (33 kg) efficiency was higher at 32°C than at 10°C, whereas in the larger pigs (over 68 kg) efficiency was much lower at 32°C. The group observed from weaning to 91 kg reflected a cross section of sizes and, therefore, an averaging out of the gross efficiency changes of smaller and larger pigs. The marked decrease in efficiency for the larger pigs probably resulted from a decrease in appetite, coupled with an increase in the expenditure of energy in thermoregulation, since their comfort zone is at a lower range than for young pigs. A further illustration comes from a comparison of pigs of similar breeding fed the same rations in large swine rearing units located on the north coast of Puerto Rico (hot) and Nebraska (temperate). The pigs in Puerto Rico required 11% more feed per unit of gain.

The two series of experiments described earlier, dealing with Shorthorn heifers maintained on a high energy ration at 32°C for 95 or 200 days (Figure 4.2), illustrate the influence of thermal stress on efficiency of feed utilization. In both tests the groups were offered the same high energy ration at the rate of 9.0 kg TDN (total digestible nutrients) per 100 kg of body weight. This level of feeding gave average daily body weight gains of 0.81 kg prior to the onset of the heat stress. At 32°C feed refusals were small and lasted only a short period.

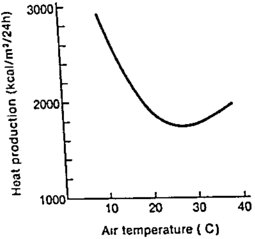

FIGURE 4 3
Influence of air temperature on body heat production of shorn sheep fed at a high level (Data from Armstrong *et al* 1959)

TABLE 4 2
Effects of two levels of temperature on gross efficiency of swine of various weights

Test	Kg feed/100 kg gain	
	10°C	*32°C*
68 kg pigs 32-day trial	1089	2142
Weaning to 91 kg body weight	840	873
75 to 89 kg initial weight, 28-day trial	869	1005
33 kg initial wt, 32-day trial	1034	814

Source Adapted from Warwick, 1958.

There was no indication of a significant change in digestibility of dry matter or rate of passage through the digestive tract. But in the early weeks the utilization of feed energy for gains was markedly reduced (−75% in the winter group and −50% in the summer group) The recovery to near the original level of gain of the "summer" heifers was much more rapid than that of the "winter" group (75 vs 170 days) This indicated the summer heifers were better prepared for the change in environment. The highest level of gain in both groups at the 32°C temperature was 0 7 kg per day—which suggests the maximum efficiency of energy utilization for gain was 12% below that of 17–21°C

In the other series of experiments with lactating Holstein cows (Table 4 1), it was found that the efficiency of utilization of digestible energy for milk yield was 60% at 21°C, but only 40% after 7 days at 32°C, and 31% after 14 days The average daily consumption of digestible energy (DE) declined about 16% at 32°C, but the daily out

put of milk energy (solids corrected milk) declined more than 22%; hence, the cows continued to consume more energy than they needed for body maintenance and production under the stress conditions but gave poorer returns. These findings clearly show that thermal stress would have the same wasteful effect in the energetics of production as shivering in the cold.

Reports from the University of Missouri (Kibler *et al.*, 1949, and Kibler and Brody, 1956) showed marked declines in metabolic heat production of lactating cows with rising ambient temperature. These reports, along with the suggestions by the National Research Council (NRC) and the Food and Agriculture Organization (FAO) based on food intakes in tropical countries, of a decrease in caloric requirements for man of 5% for every 10°C above the base temperature of 20°C (NRC) or 10°C (FAO), have led to the general assumption that total caloric requirements have a negative relationship to temperature. But this assumption has been contradicted by the work of Consolazio and Shapiro (1964). Their studies showed that the calories required per hour by a resting man at 40°C were 8.5% higher than those at 26°C, and for similar work performed in the two environments, the caloric requirements were 18.0% higher in the hot environment. They concluded that the significant increase in energy requirements under high temperature conditions was brought about by a combination of increased action of the blood in heat transport, increased action of the sweat glands, and increased metabolic rate due to the elevation of body temperature.

The experimental evidence cited above suggests that cattle, too, may have to make increased energy expenditures to combat thermal stress. (The observed decrease in energy intake by the cows in Table 4.1 probably resulted from a combination of the effect of the 32°C on the appetite center and the interference with feeding by high respiratory rates.) These findings lead to the premise that in hot climates the cost of producing a unit of energy, measured on an input-output basis, will be higher than in cool climates because thermal stress increases the animal's maintenance requirements. Although direct determinations of daily maintenance requirements have not yet been made, indirect evidence indicates that requirements for a 450 kg cow would vary with ambient temperature approximately as shown in Figure 4.4. Based on this hypothesis, extremely high temperatures would require as much extra feed to maintain a constant level of performance as extremely low temperatures. The changes in maintenance requirements portrayed in Figure 4.4 normally go unrecognized except as expressed as a decline in the input-output ratio of feed to growth (Table 4.2) or milk yield (Table 4.1).

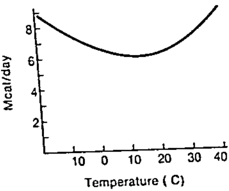

FIGURE 4 4
Likely changes in daily maintenance requirements (Mcal/day) for 450 kg cow with changing ambient temperature

Other tests under field conditions in Maryland, Louisiana, Florida, and Puerto Rico have shown similar depressions in efficiency of energy utilization for productive processes under high temperature conditions During the period June–September, lactating cows in Maryland were 10% less efficient in the use of digestible energy for milk production than during the period December–March In Louisiana lactating cows were 12% lower in gross efficiency in the period July–August than in April–May

From experiments with controlled temperature ranges, it appears that the efficiency of feed utilization by poultry is also subject to marked fluctuations because of high temperatures Adult chickens appear to do best when reared in the range of 13–21°C, with best efficiency of feed conversion occurring at about 18°C (Payne, 1966) The optimum for laying hens is 13–15°C, but between 10 and 29°C there is no serious influence on production Temperatures less than 7°C or greater than 29°C cause smaller egg size and increased mortality Like young pigs, young poultry have a narrower but higher temperature than adults for best efficiency Chicks under 4 weeks of age do best at 27–30°C, while 5 to 10 weeks old chicks make their best gains at 18–27°C Similar fluctuations in efficiency seem to occur in commercial production units Operators in Florida found that 0 09 kg more feed was required to produce a unit of gain in broilers in the period June–August than in November–April

From the preponderance of existing evidence we can conclude that the direct influence of high temperatures brings about a reduction in efficiency in the utilization of feed energy for productive processes Not only do animals eat less, but they return less per unit of intake Another way of describing the influence is to say that in warm climates, generally, "chemical costs" for a unit of livestock product are higher than in cooler climates because a portion—dependent upon age, size of animal, stage of lactation, and level of feeding—is siphoned off for the processes required to dissipate body heat.

GROWTH

Many experiments conducted under controlled temperature conditions have demonstrated a retardation in growth rate at high temperatures, the degree of retardation depending upon the age and size of the animals and the level of ambient temperature. For example, the optimum temperature range for swine 45 kg or larger is in the range of 21–24°C, while that for baby pigs is 27–29°C. The rate of gain for 45–90 kg pigs will be depressed 40–50% at 4–5°C, 25% at 27°C, and 40% at 32°C. An environmental temperature of 38°C will decrease gains by 80% or even bring about losses in weight, depending on the size of the animal (Figure 4.1). Level of humidity is also a critical factor in the growth rate of swine, particularly at 27°C or above.

Gains in lambs were markedly lower at 27°C than at 4°C, although the feed per pound of gain required at the higher temperature was less. The type of ration—i.e., the ratio of roughage to concentrate—seemed to modify significantly the influence of temperature. At 27°C lambs receiving a ration of 60% concentrate and 40% roughage gained as well as those on 40% concentrate and 60% roughage at 4°C. Another series of experiments with lambs 12–14 weeks of age showed that feed intake declined 73% at the end of 2 weeks when the lambs were exposed to 32°C. The lowered feed intakes were offset by a fourfold increase in water intake; hence, gains were not as low as might be expected. After 4 weeks at 32°C, 8 of the 16 lambs returned to near normal levels of feed intake and gains. The remaining 8 continued at low levels of feed consumption, but with very high water intake. In the latter group, 4 developed extreme diuresis and eventually died from starvation (McDowell, 1966).

The pairs of identical twin heifers separated and raised in New Zealand or Fiji on similar feeding programs showed some growth differences (Hancock and Payne, 1955). The Fiji group which had experienced a setback due to transport and quarantine, averaged about 9.6% lighter than the New Zealand group at first calving. But when the initial setback in growth rate following transport was taken into consideration, the differences between the environments were small. There may have been some difference, however, in body composition, as the Fiji heifers had higher intakes of water. The Fiji heifers had smaller skeletal dimensions except for heart girth, which was larger. The larger heart girth was attributed to the animals' drinking about twice as much water in Fiji as in New Zealand.

Table 4.3 shows the results of growth rate studies in which 6 breeds of dairy and beef heifers were reared at 10°C or 27°C for approximately 10 months. Of the beef breeds, the Brahman heifers grew

TABLE 4 3
Effects of temperature on the weight gains of heifers of various breeds

Breed	Temperature (°C) 10[a]	27
INITIAL WEIGHT AT 3 MONTHS (KG)		
Santa Gertrudis	93	89
Brahman	88	90
Shorthorn	67	61
Jersey	66	57
Brown Swiss	74	89
Holstein	104	95
AVERAGE WEIGHT AT 12 MONTHS (KG)		
Santa Gertrudis	343	313
Brahman	286	298
Shorthorn	299	209
Jersey	220	217
Brown Swiss	326	334
Holstein	360	326
RATIO OF CHANGE IN WEIGHT 3 TO 12 MONTHS		
Santa Gertrudis	2.69	2 52
Brahman	2 25	2 30
Shorthorn	3 45	2 41
Jersey	2 35	2 83
	(2.10–2 81)[b]	(2 24–3 53)
Brown Swiss	3.35	2 75
	(2.70–3 67)	(2 60–2 87)
Holstein	2.48	2 42
	(2 07–2.80)	(2 14–2 58)

Source Data from Ragsdale et al 1957 Johnson and Ragsdale, 1959
[a]Open shed cond tions w th no control of temperature (Shed was partly open at all times, but cycles of temperature d d not reach the extremes of the outside diurnal cycle for Columbia, Missouri)
[b]Range

more rapidly at 27°C than at 10°C, the Shorthorns grew far more rapidly at 10°C than at 27°C, and the Santa Gertrudis heifers grew equally well at both temperatures Of the three dairy breeds, the Holstein and Jersey heifers showed decreased growth rate at 27°C, but not the Brown Swiss In these experiments there were only three heifers per breed on each treatment and there were appreciable differences in the initial weights within breed groups between temperature regimes

In three of the breeds (Shorthorn, Jersey, and Holstein) the lightest animals were assigned to the 27°C environment (Table 4.3). These differences may have seriously affected the findings for Shorthorns and Jerseys. When the differences in initial weights and inherent differences in growth rate among breeds are accounted for by the use of ratio of change in weight from 3 to 12 months rather than absolute weights, the results are somewhat different (Table 4.3). Although the Shorthorns showed better gain ratios at 10°C than at 27°C, they did as well at 27°C as two of the other breeds. The Jerseys did better than the Brown Swiss at 27°C, and the Holsteins did equally well at both temperatures. The variation within each temperature group among the individuals of the three dairy breeds was too large to show very clearly the effect of 27°C temperature on growth rate. High temperatures probably have some influence on the growth rate of cattle, but the extent of this influence is not yet known. And the effects of parasite infestation, poor quality and inadequate feed, and health problems prevailing in the warm climates no doubt far outweigh the direct effects of temperature conditions.

What is probably more important than the influence of environmental temperature on weight gain is its apparent influence on body conformation. For instance, Holstein females of similar breeding in Maryland and Louisiana differed in body weight by approximately 50 kg at 25 months of age, but the Louisiana females were significantly shorter in body length and height at withers than the Maryland paternal half-sibs. The two groups received comparable feeding; but the cattle in Maryland developed larger frames and carried little fat, whereas those in Louisiana showed a rather high degree of fleshing. The reason for these differences is unknown.

A decreased weight-growth rate and smaller adult size, provides the animal a large surface area in relation to its mass. This might be regarded as a form of acclimation to a high environmental temperature, but if it occurs because the environment is so severe that homeostatic mechanisms are incapable of maintaining near the normal functioning of physiological processes any advantage that small size may itself confer is probably inconsequential in comparison with the loss of fitness that it represents. In other words, animals whose growth rates are not reduced at high environmental temperatures are apparently more fit than animals whose growth rates are reduced.

Although it is accepted that genetically small animals (e.g., Red Sindhi cattle) are better adapted to high temperatures than genetically large ones (e.g., Brown Swiss cattle), it does not necessarily follow that an environmentally reduced growth in weight is an adaptive response to thermal stress. In fact, there is evidence to the contrary. Even

though animals reared at high temperature conditions show less response in heat tolerance tests than animals reared under cool conditions (Johnson, 1967), the capacity to acclimatize appears best in the animals whose growth is least reduced Such relationships have been demonstrated on several occasions with mice (Harrison, 1959) What this means in large animals is that if, for example, Brown Swiss females or other breeds were reared at two temperatures—cool and hot—then both groups shifted to a hotter environment, the group reared at hot temperatures would have lower body temperatures but their feed intake and growth rate would be as much impaired as those of the animals reared at cool temperatures This is because the fitness of the heat reared animals was reduced

MILK PRODUCTION

The effects of temperature on milk production are probably the most widely publicized, the reports from field and laboratory experiments number in the hundreds All are in agreement that elevated ambient temperatures may seriously reduce the feed intake of lactating cows, resulting in lowered milk yields

Although the best temperature for lactating cows is 10–18°C, no significant decline in milk yield is usually evident under cold conditions until the temperature drops to about −12°C On the other hand, the level of milk yield is very sensitive to elevated temperatures, with measurable declines occurring in high producing cows at 24°C The level of temperature at which significant depressions will occur is, of course, dependent upon the level of production and the animal's size, stage of lactation, and genetic potential for milk yield

Figure 4 5 shows the estimated effects of various levels of temperature, humidity, and thermal radiation on the ratio of energy intake (Mcal 10^3/annum) to milk yield (kg 10^3/annum) for 3 breed groups—Zebus (Z), Zebu European crossbreds (X), and Holsteins (H) The upper limits of the curves represent the average annual yields achieved by selected herds of 100 or more cows of each type kept under excellent management regimes The input output ratios are based on a constant proportion of therms of energy for maintenance (8 0 Mcal per day for a 500 kg Holstein and 4 1 Mcal per day for a 295 kg Zebu) plus the proportion of energy consumed for milk yield (0 13–0 19 Mcal/kg milk), depending on the level of production The horizontal lines portray the influence of various levels of temperature, relative humidity, and thermal radiation on yields The locations of the lines are derived from compilations of experiments conducted in climatic controlled

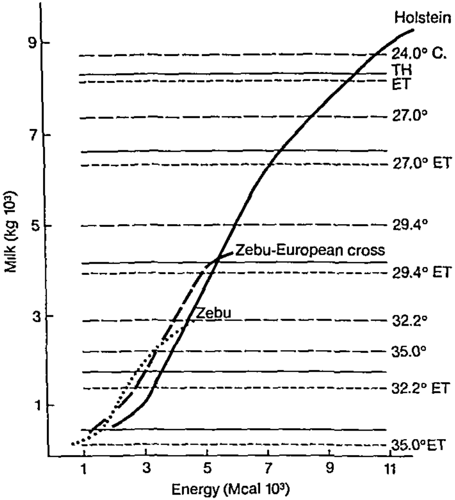

FIGURE 4.5
Influence of various levels of temperature, relative humidity, and thermal radiation on energy intake and milk yield of Zebu (Z), Zebu-European crossbred (X), and Holstein (H) cows. °C-temperature effects with relative humidity < 50%; TH-humidity > 60%; and ET-additional estimated effect of radiation. (From McDowell, 1967, Fig. 5 P. 285. *Ground level climatology*. Pub. 86. Copyright 1967 by the American Association for the Advancement of Science).

laboratories (University of Missouri, Louisiana State University, and the U.S. Department of Agriculture) as well as field experiments in Louisiana and India. The 24.0, 27.0, 29.4, 32.2 and 35.0 lines represent the expected depressions in milk yields per lactation at these temperature conditions when the relative humidity is 50% or less. The "TH" lines represent the five temperatures with relative humidity >60%. The "ET" or "effective temperature" lines include an estimate of the additional impact of average daily solar radiation at the various temperature levels. For example, the 29.4°C line shows that expected lactation milk yield may be depressed to 5000 kg for Holsteins. The "TH" line for this temperature is 4277 kg and the "ET" is 4045. This signifies that under hot, humid conditions (29.4 ET), the potential

TABLE 4 4
Relation of milk yield to various ambient temperature levels for Criollo and Brown Swiss herdmates under farm conditions in Venezuela

Temperature (°C)	*Milk yield/day (kg)*	
	Criollo	*Swiss*
23	8 2	13 4
24	7 6	13 2
25	7 3	13 1
26	7 2	13 0
26+	7 1	12 1

milk yield of Holsteins would probably be depressed about 50%, but the performance of crossbreds (X) and pure Zebus (Z) would not be seriously impaired Still, the total yield of the Holstein would equal or exceed those of the other two groups

Table 4 4 illustrates the effects of temperature on the milk yields of Criollo (indigenous breed) and Brown Swiss cows in the same herd in Venezuela The Criollo had lower yields at all temperatures Their decline was about 12% when the temperature increased from 23 to 26°C, as compared to 9% for Brown Swiss

The evidence presented demonstrates that the condemnation of European breeds because of low milk yield under hot conditions is not warranted, except where the total energy supply is less than required to maintain the larger animal Where the energy supply is limited to 3000 Mcal per year, a small to medium size animal would have a higher net efficiency For this reason selection of breeds may thus depend more on the total feed supplies available than other characteristics There is no question that improved breeds, because of their better genetic capabilities for milk production, would be more satisfactory in hot climates when 7000 Mcal of energy could be supplied per animal per year

Of course, there is some degree of variation within breed groups in the depression of milk yield in response to rising ambient temperatures, but there is no effective way of identifying those showing minimum declines due to the confounding factors of level of production, stage of lactation, age, and size One report (Johnson, 1967) concluded that the effects of high temperature on milk yield under controlled temperature conditions depended on the degree of heat tolerance of the cow and on the level of milk production This was based on the observation that milk yield decreased in all the cows

during the first 2 weeks at 29°C, then recovered during the following 7 weeks in three "heat-tolerant cows" but not in three "heat-intolerant cows." This hints of some variance within the Holstein breed but there still remains the confounding factors noted previously.

Until there are more extensive data on many more animals kept in similar environments, it will not be possible to distinguish effectively between the direct effect of warm climates on lactating cows and the indirect effects as mediated through the feed supplies.

MILK COMPOSITION

As might be expected, the yield of milk fat of cows exposed to thermal stress declines with decreasing milk yield. Hancock (1954), in a review, cited numerous experiments that recorded decreases in yield of milk fat under high environmental temperatures. In the New Zealand-Fiji experiment mentioned above, the twins in Fiji produced less milk fat. Under hot-room conditions at the University of Missouri, the milk fat yield of Holstein cows declined at temperatures above 27°C. The milk fat yield of various crossbred cows in Tasmania declined at temperatures around 28°C. Studies of the fatty acid composition of milk fat under controlled high temperatures showed that any external heat load that raised rectal temperature by 1°C or more caused changes in the characteristics of milk fat. In particular, the content of lower chain fatty acids decreased, whereas, that of palmitic and stearic acids increased. The reason for the shifts in the ratios of fatty acids is unknown. Nevertheless, these shifts can be of practical significance as they influence the quality of the milk for cheese making.

High ambient temperatures appear to have a more marked influence on the solids-not-fat (SNF) content of milk than on milk fat. In one series of experiments, SNF percentages of 8.26, 8.06, 7.88, and 7.58 were recorded for the same cows, along with a parallel decline in casein percentage, at environmental temperatures of 4, 15, 27, and 35°C, respectively, (Regan and Richardson, 1938). During the summer months in Louisiana it has been estimated that more than two-thirds of the milk from herds with predominately Holstein breeding fail to meet the 8.5% minimum in SNF set by the state. The amount of milk penalized for low SNF content increases as the summer progresses; but it is difficult to discern how much the low SNF content results from decline in quality of the forages available and how much from direct thermal stress on the cows. Holsteins in northern Colombia and Venezuela averaged 8.08% SNF, which is about 0.70% below the

breed average in cooler climates The SNF content of milk from indigenous cattle is normally 8 6% or greater, but how much higher it might be in cooler climates is unknown Water buffaloes, sheep, and goats all have a rather high SNF content under warm conditions A large field trial with Holsteins in the U S during the summer months showed that at temperatures 25°C and above, the simple correlation of percentage SNF and temperature was – 61, while that for temperature and milk fat percentage was – 23 and for percent protein – 34

Thermal stress also appears to bring about some decrease in percentage of lactose and acidity in the milk, lowers its level of panto thenic acids and lowers its freezing point It increases the pH and levels of ascorbic acid and riboflavin But it has little effect on the salt balance or the carotenoid and vitamin-A levels in milk fat

Currently, the general conclusion is that the decline in the milk yield of cows exposed to thermal stress is predominantly the result of heat induced depression in feed intake–that is, an indirect effect of climate This conclusion derives from observations that changes in composition accompanying climate are similar to those resulting from non climatic factors, such as feed intake or fever accompanying disease Feed supply may be as important for milk composition as for milk yield in warm climates, except perhaps under the most severe environmental conditions

REPRODUCTION

High environmental temperatures can cause a decline in the reproductive efficiency of both males and females through decreased gametogenesis, libido, estrus, ovulation, fertilization, implantation, embryo survival, gestation length, and mothering ability of the female, as well as increased problems at parturition time

Male

Numerous reports concerning the influence of thermal stress on the reproductive efficiency of males agree that high temperatures can in terfere with the process of spermatogenesis in all species of livestock

Ambient temperatures above 29°C are for the most part severe enough to impair spermatogenesis and the quality of the semen There also seems to be a positive relationship between the number of abnormal and dead sperm and the level of environmental tempera

ture. When the relative humidity exceeds 70% at 27°C and above, humidity becomes an additional inhibitor.

The scrota of sheep, cattle, goats, and buffaloes all have mechanisms which help to protect the testes from overheating. Through actions of these mechanisms, the critical temperature for the initiation of sweating is lower for the scrotum than for the trunk. And the suspensory muscles can be relaxed to allow the scrotum to hang lower, which may aid in cooling by conduction. In spite of these features, the semen quality of these species varies inversely with environmental temperature.

Under grazing conditions, extending the scrotum may aid in maintaining semen quality, but it has practical disadvantages. If the scrotum drops to a low position it impairs movement, especially in coarse grass and shrubs. Zebu bulls tend to relax the crestmaster muscles but not the dartos, thus allowing the scrotum to tilt instead of hanging low as often occurs in bulls of European breeds.

Of the semen samples from bulls kept in an air-conditioned laboratory at 27°C, 91% were suitable for artificial breeding; whereas, the corresponding figure for semen from bulls kept in a barn under natural conditions prevailing in Louisiana during the summer was only 47%. There is some evidence, too, of an interaction between temperature and daily photoperiod. From May to October the percent of shippable ejaculates for dairy bulls in Louisiana under regular barn conditions and photoperiod averaged only 18%. Increasing the photoperiod from 14 to 16 hours gave 33% satisfactory ejaculates; but reducing the temperature from 24–27°C mean daily temperature to 18°C gave 76% shippable semen (Roussel *et al.*, 1963).

Research in temperature controlled laboratories has shown that thermal stress does not seriously impair libido in the males of cattle, buffalo, goat, and swine, but does impede libido in rams with wool covering. Even so, under field conditions males frequently undergo periods of poor libido for at least two reasons. The persistent tropical heat tends to reduce activity of the males. They may actually divest themselves from the area being grazed by the females. And in the field, much of the males' time and energy must be devoted to seeking feed. By contrast, exposure to thermal stress lasts only a few hours or days in the laboratory, and feed is readily available.

There is some proof that under hot conditions the extent of wool covering on the scrota of rams influences the percentage of abnormal cells in the semen. Breeds with heavily wooled scrota (e.g., Romney Marsh) are particularly susceptible. Although heavily wooled scrota are more characteristic of some breeds than others, the variation within breeds could be important in good ram performance. Experi-

ments with Merino rams in Australia showed that the percentage of abnormal cells was highest in rams with heavy scrotal wool cover (7 cm and more in depth) By the fifteenth day of exposure to 40°C this group had 23% pyriform (abnormal) cells, whereas those with intermediate scrotal cover (3 cm) had only 7% pyriform cells Even though semen returned to normal in both groups by 28 days after exposure to thermal stress, it was concluded that the proportion of abnormal cells in the semen of the heavily wooled rams would have impaired breeding efficiency (Rathore, 1969)

Female

Severe thermal stress will cause a cessation of estrus and even ovulation in cattle and sheep High temperatures also cause a shortening of the duration of visible expression of estrus (see Chapter 12) and decreased embryo survival Sheep embryos exposed to as little as 1 1°C temperature over normal body temperature during early development (first or second cell division) will not survive, but similar exposure at later stages will not affect embryo survival There is evidence too, that exposure of sheep spermatozoa to high temperature decreases survival rate of embryos produced from eggs fertilized by the treated sperm

The effects of temperature stress on fertility of sheep have thus been found to occur during a relatively short period following fertilization Protection from temperature stress during this critical period has resulted in an increased reproduction rate in sheep Ewes kept as long as 11 hours daily at a temperature of 40°C during the last 3 months of pregnancy had smaller lambs than controls, but even at this high level of thermal stress there were no abortions

In hot, dry areas of the southwestern U S , protection of cattle from heat stress for 100 hours or more following breeding increased conception rate 2–70% These results suggest that a similar critical period in embryo development exists in this species

Level of body temperature of the cow at the time of insemination may be important in conception In Louisiana it was found that if the rectal temperature of a dairy cow exceeded 39°C at the time of breeding, conception rate was near zero When body temperature was high, the duration of visible evidence of estrus was short These findings led to the recommendation that during the summer months cows might be bred with reasonable success providing their body temperatures are <39°C

The offspring of females in hot climates are usually somewhat lighter at birth than similar offspring in cool climates Female calves

born during the summer months are, in general, about 5% lighter. In Australia, lambs born during the summer months were smaller than those born in the cooler months. (The animals born during the hot season may or may not remain smaller throughout life depending on level of feeding at later ages). The birth weight of swine in Puerto Rico from sows of the same breeding, on similar rations, was 6% smaller than in Nebraska. The number of abnormally small pigs was higher in Puerto Rico. The reasons for the depression in birth weight are not understood. No doubt several factors are involved. Females of all livestock species tend to be smaller in the tropics. Since size of dam is the major factor controlling size of offspring, we expect this to contribute to the difference between climatic zones. Too, tropical conditions no doubt have some influence on the physiological functions of the mother, including level of endocrine secretion, which in turn are expressed in size of offspring. The fact that offspring born in the cool season in subtropical areas are slightly smaller than those born in temperate areas, but those born in the hot season are much smaller, supports the theory that several factors are involved.

In temperate areas, low hemoglobin values in cattle have been associated with poor reproduction. Values below 9.8 g/100 ml of blood are associated with anestrus and repeat breeding. Females with hemoglobin levels of 10.6 g/100 ml show normal reproductive performance, but females with less than 9.0 g/100 ml show no signs of estrus. The low values in the temperate areas are attributed to possible cobalt, copper, or phosphorus deficiencies, or parasites, such as lice. Cattle and other farm livestock in the tropics frequently have hemoglobin values less than 10.0 g/100 m, probably because of mineral deficiencies, parasites or thermal stress. Although low hemoglobin values may be a factor in reproduction rates in hot climates, the critical levels have not been identified.

Involution of the reproductive tract may be delayed indirectly as the result of thermal stress principally through hormone imbalance. Continuous thermal stress may also cause a cow to produce a small corpus luteum that will bring on estrus but the corpus never fully develops so ovulation does not occur. If insemination is made, it will be wasted effort. Another problem of hormonal imbalance resulting from thermal stress is insufficient progesterone secretion by the corpus luteum to maintain pregnancy. This condition is frequently associated with embryonic motility because the pregnancy lasts no more than 20–50 days.

In most areas where the mean daily temperature exceeds 24°C for two or more months, some decline in breeding efficiency is likely to occur in dairy herds. For instance, 20–40% more services were required for conception from July to October in the U.S. than from

TABLE 4 5
Influence of season on measures of fertility in a Louisiana dairy herd

Measure	*Dec–Feb*	*Mar–May*	*Ju–Aug*	*Sept–Nov*
Days from calving to first estrus	37	44	55	49
Services per conception	1 5	1 7	1 8	1 6
Days from first service to conception	31	34	49	40

December to March The longer the duration of the stress period the more pronounced the effect of season on breeding efficiency In subtropical areas, such as southern Louisiana, season has a definite influence on time of onset of estrus, services required for conception, and length of the breeding period (Table 4 5) Seasonal limitations are important in the reproductive performance of European breeds of cattle and their crosses with Zebus But high temperatures do not seem to be the limiting factor in Brahman cattle, Brahmans appear to be more affected by the cooler temperatures of the winter months

A summary made in 14 southern states of the U S to identify some causes of low breeding efficiency and poor viability revealed that calving percentages of beef herds averaged about 77% for number born but 69% for number weaned On the average, cows nursing a calf when bred weaned approximately 4% more calves during the subsequent year than did cows that were dry when bred Four year old cows weaned 4 5% more calves than older or younger cows, while yearlings were approximately 1% below average Pasture mating of cows resulted in approximately 36% more calves than did artificial insemination Cows that did not conceive during the regular spring breeding season that were suckling calves had a lower pregnancy percentage (43%) in a subsequent 27-day dry breeding period than cows nursing calves (62%) Cows of European breeds, bred when nursing a calf, had a larger subsequent calf crop, while in Brahman cows the reverse took place, illustrating a breed by lactation interaction Lactating cows of the Angus and Hereford breeds exceeded the dry cows in weaning percentage by about 80%, while in the other breeds—Brahman, Brangus, Santa Gertrudis, and Shorthorn—the dry cows had the highest calving rate, ranging from about 4% advantage for dry Shorthorns up to 15% in Santa Gertrudis The results of this survey indicate that in subtropical areas, season, breed, age and lactation are important to reproductive efficiency of beef herds

Sheep in the southern region of the U.S. exhibit definite seasonal patterns of reproductive performance. This is evident not only in the number of ewes cycling but in the ovulation rate as well. The ratio between daylight and darkness or photoperiod seems to be a major factor influencing seasonal trends in reproductive activity. In the southern U.S. reproduction rate and lamb survival have been generally increased when ewes were kept in confinement immediately before and after breeding. Rambouillet, Dorset, and Merino ewes have exhibited the least seasonal restrictions in their breeding habits by conditions in the warmer climates.

It has been reported that the frequency of stillbirths and problems of dystocia (difficult parturition) in cattle are higher during hot periods. But what role temperature plays is not discernible. Current evidence suggests that the cause may be an endocrine imbalance brought about by thermal stress on the female during the late stages of pregnancy.

Thermal stress, as it influences behavior, can contribute to loss of offspring. For instance, sows fret and move about during parturition in hot weather, resulting in a loss of piglets due to trampling. To calm the sow, swine producers often use a "snout cooler"—a small air conditioning unit with a cone the sow can place her snout into. Although the small unit does not provide a large amount of cooling, it has the important psychological effect of keeping the sow quiet.

Chapter 12 deals with some of the measures man can implement to decrease inefficiencies of reproduction.

DRAFT CAPACITY

Even though there is no experimental evidence on changes in the draft capacity of oxen or buffaloes with rising ambient temperature, it is logical to assume a negative relationship between performance and high temperatures. High temperatures affect performance directly by causing animals to move more slowly. Since feed intake is likely to decline and a greater portion of the energy is likely to be expended for thermoregulation, the depression in efficiency of work performance would no doubt be similar to that expected for milk yields.

ENDOCRINE FUNCTION

The importance of temperature in relation to the functioning of endocrine glands was discussed in the section on heat regulation in Chap-

ter 3 Apparently, of the most practical significance is the effect of temperature on the thyroid and its consequent influences on appetite and performance A series of experiments illustrating the potential involvement was conducted at Louisiana State University, where thyroprotein was fed to lactating cows at 25 and 35°C Thyroprotein serves as a stimulant to appetite and has been advocated a number of times as a means of increasing milk yield or preventing declines under thermal stress In the Louisiana experiments, thyroprotein was fed at the rate of 3 grams per 100 kg body weight per day There was an increase in milk yield of 19% the first week at the 35°C temperature for the thyroprotein fed cows, but afterwards milk yield decreased 30% below the peak level and the animals lost weight very rapidly The control group decreased 20% in production by the end of the third week, with no appreciable loss in body weight Hence, the control cows produced more milk during the experimental period These findings suggest that the thyroid gland tends to decrease in activity with rising temperature But little can be done about reversing depressed appetites under thermal stress

There has been some experimentation with the use of hormones and tranquilizers to change animal responses to hot environments, but the evidence for their usefulness is not conclusive In one series of experiments with sheep, injections of tranquilizers brought about the death of the animals under heat stress

Although the preponderance of the experimental evidence shows that high temperature and high humidity conditions may have marked direct effects on feed intake and, indirectly, on performance, the conclusion is that unless the stress occasion causes an elevated body temperature for a considerable time, it is highly unlikely that performance will be depressed to a point of serious economic significance This statement holds provided available feed supplies are adequate in quality and quantity Animal performance is generally lower in warm climates than in temperate areas, but we must lay the blame where it belongs, namely in the tropical environment having its greatest influence in an indirect fashion rather than of a direct nature

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5

Determining the Suitability of Livestock to Warm Climates

Another aspect important to livestock production in warm climates is how best to assess the merits of livestock for performance under the conditions prevailing within a locality For stock already existing within a herd or flock, the best indicator of suitability to the total environment is performance This constitutes our primary expression of adaptation when compared to some predetermined expectation in the mind of the livestock operator, based on his previous experiences, on some level of performance attained by a neighbor, or on an ideal derived from performance elsewhere – e g , the milk production of the average Holstein cow in New York State However, there are two major shortcomings of assessing suitability of animals by performance alone (1) these measures generally come late in the animal's life, and (2) such measures of performance as total lactation milk yield or time to reach 400 kg body weight do not show very clearly how the environment is affecting the animal's physiological processes, and thus its efficiency Some index of the animal's probable later performance, that could be made early in the animal's life, would hasten the selection processes for genetic improvement And appropriate identification of such things as stress imposed by seasonal fluctua-

tions in the environment could be useful in determining whether or not adjustments in management practices should be made.

If the locally available animals perform poorly and changing the type of animals seems desirable, the question becomes that of how to make the wisest decisions. Should physiological or anatomical traits be considered? Can tests made in another environment predict the performance of a group of animals in a tropical environment? This chapter will be concerned with some of the measures employed as attempts to characterize the adaptation of animals to hot environments.

ASSESSMENT OF ADAPTABILITY

Ideally, measures of an animal's adaptability to a particular environment should have a high correlation with performance. Just as an athlete's performance can usually be predicted better by testing pulse rate changes than by testing endurance, an animal's performance can be predicted better by some tests of adaptability than by others. For the most part the assessments of animal suitability to hot environments have fallen into two classifications: "physiological adaptability," which describes the animal's tolerance to a hot environment as determined principally by shifts in heat balance, and "performance adaptability," which describes changes in the animal's performance in a hot environment. Over the past three decades a great deal of attention has been given by physiologists and others to (1) identification of breeds or strains that exhibit the least shift in heat balance of the body when exposed to thermal stress, and (2) identification of physiological and anatomical traits associated with the promotion of heat loss. A high positive correlation has been assumed to exist between minimum shifts in the heat balance of the animal's body and performance in warm climates. On this premise, a number of indices have been proposed as aids in selection of animal based on either field or psychrometric laboratory experiments. Several of the proposed indices are listed in Table 5.1.

FIELD TESTS

The most prominent index developed from field data is identified as the "Iberia Heat Tolerance Test." In this index, a coefficient of tolerance to heat stress (CFHT) is calculated from the difference between a cow's recorded body temperature after a period of exposure to sum-

TABLE 5 1
Various field and laboratory tests that have been used or advocated for assessing the adaptability of cattle to hot environments

Common name of test	Basis of determination	Authors
	FIELD	
Water loss	Water loss by respiration, urine, feces, and surface	Rhoad, 1944
Iberia heat tolerance test	Rectal temperature	Rhoad, 1940
Coefficient of adaptability test	Rectal temperature and respiration rate	Benezra, 1954
Felting test	Hair coat	Bonsma, 1949
Walking and water deprivation test	Distance and water consumption	Bonsma, 1949
Exercise and cooling efficiency test	Rectal temperature	Dowling, 1956
Hair coat score	Hair coat quality	Turner and Schleger, 1950
	LABORATORY	
R value heat tolerance test	Rectal temperature	Lee and Phillips, 1948
Ratios of evaporation	Skin and respiratory evaporation at two temperatures	Yeck and Kibler, 1958
Stress strain	Relative strain = $\frac{\text{evaporative cooling required}}{\text{maximum evaporative cooling possible}}$	Lee, 1965
Lines of equal effect	Rectal temperature, respiration rate and volume	Barrada, 1957
6-hour hot room test	Rectal temperature and respiration rate	McDowell *et al*, 1955

mer conditions and the body temperature considered normal for the cattle, using the following formula

$$\text{CFHT} = 100 - [10\,(\text{BT} - 101.0)]$$

where. CFHT = coefficient of heat tolerance, BT = average body temperature obtained under conditions of the Iberia test, 101.0 =

TABLE 5.2
The comparative tolerance of various breed groups to high temperature conditions as measured by the Iberia Heat Tolerance test applied at Jeanerette, Louisiana.[a]

Breed group	*Sex*	*Number of animals*	*Coefficient of heat tolerance*
Zebu (Brahman)	♀	7	89
½ Zebu–½ Angus	♀	19	84
⅜ Zebu–⅝ Angus	♀	8	84
Santa Gertrudis	♀	7	82
½ Africander–½ Angus	♀	22	80
Jersey	♀	34	79
¼ Zebu–¾ Angus	♀	54	77
Hereford	♂	12	73
¼ Africander–¾ Angus	♀	4	72
Angus	♀	31	59

Source: Adapted from Phillips, 1948
[a] General conditions under which the tests were made A.M. temperature, 32°C, humidity, 82.8%, wind velocity, 3.3 km/hr. P.M. temperature, 34°C, humidity, 71.7%, wind velocity, 7.2 km/hr

normal body temperature of cattle (°F), 10 = constant to convert degrees deviation in body temperature from the normal to a unit basis, and 100 = perfect efficiency in maintaining body temperature at 101.0°F.

From this formula, an animal with a body temperature of 103.8°F would have a CFHT of 72. Table 5.2 shows the probable differences in heat tolerance among breed groups. In this series of tests the Zebu, with a coefficient of 89, was considered to have the best tolerance, while the purebred Angus, with a coefficient of 59, showed the least tolerance. It was concluded that the Zebus would best withstand the high temperature and humidity conditions prevailing at Jeanerette, Louisiana during the summer months; the Zebu-European crossbreds would be intermediate; and the pure European breeds or crosses with a high proportion of European breeding (¼ Africander–¾ Angus) would be the least suitable. Based on these preliminary findings, CFHT was made routinely at the Iberia Livestock Experiment Station for a number of years and then studied in relation to certain performance variables of various breed groups (Vernon *et al.*, 1959). The correlation between the CFHT of 258 Brahman-Angus crossbred cows (initially indexed at 84) and the cows' own birth weights was near zero (−0.05), with a small negative regression, −0.15 kg. When the cows' own 6-month weights were used, the correlation was −0.06 and the regression −0.18 kg. The correlation between CFHT of dams and the birth weight of their calves was −0.11. When the average 6-month weights of the calves were used, the correlation was still near zero (0.09). Observations on 56 Africander-Angus crossbred cows (inter-

mediate in CFHT) and 16 Brahman cows (highest in CFHT) were equally inconclusive When similar correlations were made using respiration rates, the results were about the same as for CFHT It was concluded that the suitability of females for performance under the conditions in southern Louisiana could not be judged by the level of body temperatures and respiration rates collected on several days during the summer months A further conclusion was that direct selection for reproduction rate and weight of calf weaned should result in selection not only for adaptation to local conditions but for other characteristics necessary to high performance

In the "Water loss," "Coefficient of adaptability," "Walking and water deprivation," and "Exercise and cooling efficiency" tests (Table 5 1) the regression rates of certain reactions on air temperature or humidity were used for comparisons among groups and individuals. Results have given some indication of breed group differences in cattle, but additional data in several environments are needed before decisions can be made on their usefulness as indicators of superior animals Rankings from these indices have not been related to animal performance sufficiently to be enlightening

The "Felting test" and "Hair coat score" (Table 5 1) have shown reasonably good correlations between score and general performance in hot climates Although they are not direct measures of response to heat stress, in the strict sense, they provide valuable information on the animal's general capability to thrive in hot climates The tests have shown promise in identification of animals well suited to the areas where the observations were made But since they are not direct measures of response to heat stress, there is some question as to their usefulness in selection for adaptability It is not clear, for example, whether undesirable coat types—e g , the "wooly coat," which scores low on the Felting test, or the "rough coat," which scores low on the Hair coat score scale—depresses adaptation by interfering with heat loss from the skin, or whether these coats are outward signs of imbalance of internal functions related to the general physiological state of the animal

Laboratory Tests

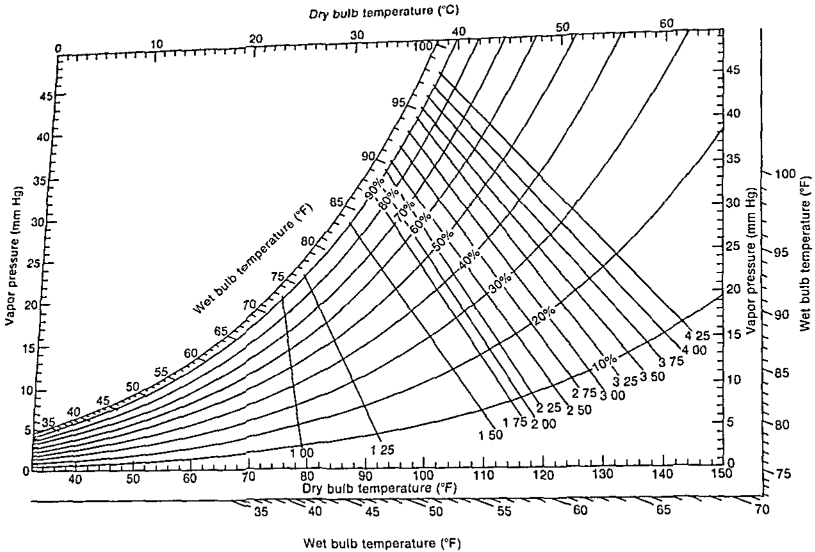
Laboratory tests have utilized standardized combinations of temperature and humidity to derive data for determining the regression rates of such reactions as rectal temperature, respiratory rate, and sweating, on various levels of air temperature and humidity These tests have

the added advantages of requiring fewer animals and permitting repetition of the temperature-humidity regimes, which gives more precise estimates of the stress-strain relation than is ordinarily possible with field data.

The "R-value heat tolerance test," "Ratios of evaporation," and "Lines of equal effect" (Table 5.1) have been used on very few individuals or groups. Barrada (1957), following models for humans, plotted "lines of equal effect" on a psychrometric chart (see Chapter 2 for description) for rectal temperature, respiratory rate, and respiratory volume. Figure 5.1 illustrates the equivalent effects of changing air temperature and relative humidity on rectal temperatures for mature dry Holstein cows. The lines for animal responses were established by repeated exposure of the same cows to a series of air temperatures with high and low levels of relative humidity (20 and 80%). Based on Barrada's data a cow would have the same level of rectal temperature (102.0°F) after exposure to an ambient temperature of 100°F with 50% relative humidity (moderate humidity) as for 91°F with high humidity (80%). Theoretically, the equivalent effects principal could be applied to almost any trait (e.g., respiration rate, milk yield or feed intake) so that if the temperature and humidity regimes were known their influence could be anticipated. Numerous charts of this nature have been prepared for human responses; but no one has as yet followed through on Barrada's preliminary work, largely because of the time and effort required to obtain sufficient data. Suitable indices of this nature would encompass many observations on breeds and, within breeds, on animals of different ages, stages of lactation, levels of yield, and stages of gestation.

The "Stress-strain index" proposed by Lee (1965) for use with animals stems from studies with humans. It will be difficult to estimate the maximum evaporative cooling possible for animals because variations in pelage and other factors have more influence on evaporation rate from animals than for man.

The "6-hour hot room test" has been used extensively in attempts to estimate the comparative responses of Jerseys and various combinations of crosses between Red Sindhi (a Zebu breed from India) and Jerseys in a subtropical area (southern Louisiana) and a temperate area (Maryland). In these tests large numbers of animals at both locations were subjected at various ages and stages of lactation to 6 hours of 40°C ambient temperature and 60% relative humidity. The objective was to ascertain the degree of rise in respiration rate and rectal temperature. The very high temperature was chosen to assure some degree of response in all animals.


Dry bulb temperature (°C)
Dry bulb temperature (°F)
Vapor pressure (mm Hg)
Vapor pressure (mm Hg)
Wet bulb temperature (°F)
Wet bulb temperature (°F)
Wet bulb temperature (°F)
90%
80%
70%
60%
50%
40%
30%
20%
10%
1 00
1 25
1 50
1 75
2 00
2 25
2 50
2 75
3 00
3 25
3 50
3 75
4 00
4 25

From tests on heifers between 10 and 22 months of age, dry cows, and lactating cows, it was found that location (Louisiana or Maryland), season, environmental temperature previous to the day of testing, stage of lactation, level of daily milk yield, and rectal temperature of the animals prior to the test period all had significant effects on the responses of all groups. Age effects were not important in either heifers or cows, but the response of the animals in a given test period was markedly influenced by the environmental conditions (season effects) they had been accustomed to prior to the thermal stress. The crossbred animals with $\frac{1}{4}$ Red Sindhi genes showed slightly less response than the pure Jerseys. The responses of $\frac{1}{2}$ crosses, first and second generation, and $\frac{3}{4}$ Red Sindhi crosses were similar but significantly less than for pure Jerseys. The ranking of the breed groups was the same for degree of rise in both rectal temperature and respiration rate. The similarity of the reactions of the $\frac{1}{2}$ and $\frac{3}{4}$ Red Sindhi crosses suggested the possibility of some heterosis for resistance to thermal stress.

The proportion of Red Sindhi breeding influenced the response of heifers to the 40°C temperature, but $\frac{1}{2}$ Red Sindhi breeding gave near maximum tolerance. However, the effects of seasonal influences on the degree of rise in body temperature and respiration were so variable, even at the same station, that at least three observations would be necessary in different seasons to classify the breed groups with any degree of precision. On the other hand, there was almost no relation between the growth rate or milk production of any of the groups and the degree of response to the 6-hour test. The correlation of rise in rectal temperature over the 6-hour period and the growth rate of the heifers ranged from −0.11 to +0.14. The relation of each animal's average response to the heat stress and her first lactation milk yield was near zero ($r = -0.03$ to $+0.18$ for rectal temperature and 0.08 to 0.21 for respiration rate). The correlation between responses of the same animal as a heifer and as a dry cow were also low: +0.14 and +0.17 for temperature and respiration, respectively.

There was no significant relation between the reactions of the same animal when lactating and when dry. Although the repeatability estimates for individuals within breed groups between various ages prior to first calving, between different lactations, and between dif-

FIGURE 5.1
Lines of equal effect on various combinations of air temperature and vapor pressure on the rectal temperature of dry Holstein cows (Rectal temperature values −100°F). (From the Ph.D. thesis of M. S. Barrada, Johns Hopkins University, 1957.)

ferent dry periods differed significantly from zero (range +0 17 to +0 39), these low values show that laboratory heat tests would be as ineffective as the Iberia heat tolerance test cited above in identifying the individuals within breed groups that might perform best under hot conditions In these studies sire effects were negligible (McDowell, 1966)

Field studies made during the summer months in Texas comparing Jersey-Brahman crosses to both Holsteins and Jerseys, and studies in Louisiana comparing Brown Swiss to Red Sindhi-Brown Swiss crosses and Holsteins to Red Sindhi-Holstein crosses, revealed that the Zebu crosses had less rise in rectal temperature and respiration rate than the pure European breeds But the relationship of level of response to milk yield was negative (−0 19 to −0 46) and of nearly equal magnitude in all groups

In all the field and laboratory tests there were occasional crossbred animals which showed a low level of response and had a high milk yield The same was true in the pure European breeds It appears that although, on the average, the responses of the Zebu (Brahman and Red Sindhi) crosses to the direct effects of high ambient temperatures were less than for pure European breeds, the degree of reaction in high yielding cows depended more on the individual than on the breed group with the frequency for a combination of high heat tolerance and productivity not being markedly improved by adding Zebu genes

The indices described are at best rather nonspecific, they indicate primarily the animal's lack of ability to maintain thermal balance or a normal state of homeostasis, or characterize the general adjustments (e g , short hair coat) the animal has made to the total environment. Rankings of breed groups from the indices may prove useful if selection is to be practiced for capability to maintain thermal balance, but the potential user must be aware that fluctuations in the environmental conditions may completely nullify recognizable improvement through selection Furthermore, because of the low repeatability of the assessments to stress made in one location, it is not likely, for example, that a CFHT score would have much value outside the environment in which the test was made, therefore it would be of little value in selecting animals highly suitable for another location

There are several other serious limitations of the indices for the purposes of selection for genetic improvement. Little consideration has been given to males, which make a much greater contribution to future generations than do individual females A rise in rectal temperature in the male may have an entirely different meaning than a

high body temperature in the lactating female. Also the indices do not include weightings for performance. The cost of gathering data is high; an extensive amount of handling is required for most tests; and in laboratory tests, expensive facilities are needed.

Since changes in heat balance of the body (measured as rectal temperature or coat characteristics) are largely effects rather than causes, a better understanding of the physiological mechanisms responsible for superior or inferior maintenance of heat balance should in the long run prove more useful. Nevertheless, some evaluation of animal discomfort, such as a rectal temperature taken in the afternoon, could serve as a guide for management. Like whether body temperature, by indicating possible interference with conception, could prove useful in determining insemination practices. However, close observation of the animal's acceptance of feed and breathing rate would provide approximately the same estimate of discomfort to the experienced observer.

Anatomical Traits

Although there has been no index proposed based solely on anatomical traits associated with the animal's capability to increase rate of heat loss, a great deal of attention has been given to anatomical traits, both by researchers and animal producers. Research along these lines has been inspired largely by the common assumption that the phenotypic characteristics of certain breed groups greatly enhance their adaptability to hot climates. For example, in the past quite a bit of emphasis was placed on the size of the ears by breeders of Zebu cattle in Brazil. It was also assumed that a single means of promoting heat loss is highly correlated with performance. This theory received a boost in the 1945–55 period, when studies were being conducted to determine whether certain traits, such as rate of skeletal development and rate of early mammary development, could be used to improve predictions of young cows subsequent performance. These experiments fell short of expectations because of the low correlations (0.00 to +0.28) between the individual characters studied and the more complex processes of growth, milk yield, and breeding efficiency. It was concluded that records of performance of the dam and other close relatives of the female under consideration were better criteria

for predicting potential capability than measures of rate of development of the individual prior to first parturition

THE EMPHASIS ON PERFORMANCE IN ASSESSING ADAPTABILITY

Since physiological adaptability is expressed in performance, the question arises, does not selecting for performance alone give sufficient consideration to physiological traits involved in maintaining heat balance? Present evidence supports primary emphasis on performance (1) The low correlations obtained thus far between an animal's heat tolerance and ability to perform suggest that livestock producers could ill afford to emphasize a single measure of the resulting strain from thermal stress in a selection index (2) The very low correlations between responses measured as shifts in heat balance suggest that physiological adaptability would not be greatly impaired by placing major emphasis on selection for performance In fact, there are indications that selection for performance (milk yield and reproduction rate) will automatically lead to selection of the most suitable animals, and presumably the most efficient for warm climates Too, there is some proof that the relation between overall adaptability and performance is positive and reasonably high (Vernon *et al*, 1959, Leckey, 1960, and FAO, 1968) (3) Selection for several traits at one time slows the progress that can be made in improving any one trait unless the traits are highly correlated (see Chapter 9) (4) The time required and costs involved in making major genetic changes in a group of livestock purely by selection, particularly with emphasis on characters of low heritability, are often prohibitive (5) There are no satisfactory estimates of heritability available on the expected rates of genetic change in the physiological traits examined so far

Experiments conducted in Britain further discourage selection experiments to change the basic mechanisms of heat regulation When indigenous sheep from a small, windswept island in the Norwegian sea were exposed to thermal stress in a controlled laboratory, the island sheep responded similarly to British breeds in elevations of body temperature and respiration rate This is not meant to imply that differences among existing breeds and species in suitability to warm climates are not important. But practical suitability to warm climates is not likely to be judged satisfactorily by measures of body temperature, respiration rate, or other physiological characteristics that vary significantly with such factors as the conditions of the general environment, age, and level of nutrition

POSSIBLE ADVANTAGES OF INDIGENOUS TYPES FOR WARM CLIMATES

Albeit the evidence reviewed does not indicate that animals indigenous to warm climates possess any outstanding traits that make them universally suitable to hot environments, the technical literature contains several hundred reports extolling the advantages of indigenous stocks over animals introduced from outside. Most of these imply that the differences in adaptability associated with various breeds are due to certain characteristics peculiar to those breeds. Certainly it is logical to assume that animals that have existed for hundreds of years in a rigorous environment have been forced to develop certain adaptates and assume special habits of behavior or they will perish. Hence, in choosing breeds or in making combinations of breeds, care should be taken to insure these traits are not overlooked. They may well be more important than the indices discussed previously. Of course, producing breed combinations depends on proper placing of emphasis. Some of the traits that ought to be given consideration are described below.

PELAGE AND SKIN CHARACTERISTICS

Cattle indigenous to tropical areas have a short hair coat in comparison to those originating in regions where there is a pronounced temperature change with season. In all breeds, age is a significant factor in follicle density, but not in length of coat or seasonal changes in hair characteristics. The hair follicle of the Zebu has a relatively stiff center core, which tends to keep it in a more erect position than that of European types, even when length of hair is approximately the same. Where rapid evaporation from the body surface is desirable, the more "open coat" of the Zebu should afford advantages (Pan, 1964).

The Criollo of Latin America, a *Bos taurus* type, probably has the shortest hair coat. At maturity the hair is sparse, especially on the neck and shoulder (DeAlba y Carrera, 1958). Some of these cattle are almost devoid of visible hair by the time they reach maturity. The cause of the loss of hair remains unknown. Studies in Brazil showed that the skin tends to thicken with age, principally the dermis. It has been suggested that with the thickening of the dermis, pressure is applied around the hair follicle, eventually causing it to die and preventing new follicles from emerging.

It has been well established that poor nutrition, disease, and parasites will cause delay in shedding of hair coat of European type cattle in the tropics There is also some evidence that the small changes in photoperiod in the tropics may cause European type cattle to fail to shed their long hair coat. However, given a reasonably good level of environment, most European types or high grades will develop and maintain a shorter hair coat in the tropics than in a cooler climate This may not be the entire story, however Figure 5 2 illustrates contrasts in hair coats—short, intermediate and long—among contemporary young Holsteins reared in Venezuela These cattle, which were second generations from imports, received excellent feeding and care, thus the variations in coat probably resulted from genotype environment interaction Observations made in a large calf rearing enterprise in Puerto Rico lends support to genetic involvement. Calves were purchased from a large number of farms at 1 to 3 days of age The animals (males, principally of Holstein breeding) were reared in confinement on a high plane of nutrition up to 385 kg weight. At 3 days of age there were no discernable differences in the hair coats of the calves, but at 6 months variations were readily apparent, with about 15% "wooly coats," 60% intermediate, and 25% very short hair (similar to that of the animal in the top portion of Figure 5 2) The wooly coated animals never reached the desired weight.

Pelage characteristics are certainly a factor to consider in introducing temperate zone breeds in to the tropics In Brazil, a significant negative correlation (−0 37) was found between depth of hair coat and milk yield in Jersey, Brown Swiss, and Holsteins The findings in South Africa and Australia on the relation of hair coat length to live weight gains, as well as on the number of ticks in pure European stocks, further support the need for extensive research on the possible genetic influences in European breeds Such research is especially important in view of the extensive use through artificial insemination of bulls from the temperate zone It may be necessary to screen bulls from the temperate zone for frequency of "wooly coats" under hot conditions, the need for this remains to be determined Long hair is not a problem in livestock improvement schemes when crossing is used, as only ⅛ to ¼ Zebu or Criollo genes are needed to insure a short coat. Figure 5 3 portrays a contrast of coat length between a pure Jersey (wooly coated) and a ½ Zebu cross

Ether extraction of residue from clipped hair or wool samples of cattle and sheep originating in tropical areas hint higher levels of secretion from the sebaceous glands More sebum tends to prevent excess drying of the superficial layers of the skin and may afford some

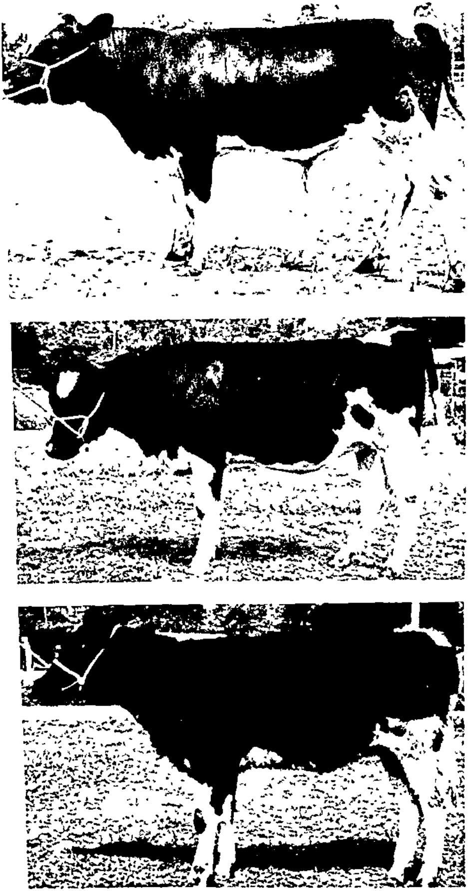


FIGURE 5.2
Variations in length of hair coat among contemporary Holsteins reared at the University of Venezuela, Maracay. (Courtesy Universidad Central de Venezuela Facultad de Agronomia, Maracay).

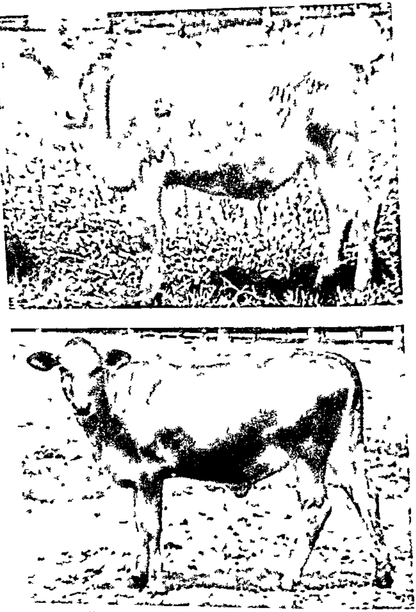


FIGURE 5.3
In southern Louisiana, Jersey heifers often have long shaggy hair coats while Red Sindhi Jersey crosses always have short coats

advantages in reflecting solar radiation and repelling vectors All breeds of livestock indigenous to hot areas have pigmented skin which avoids problems of sunburn from thermal radiation, as well as reducing susceptibility to health problems, e g , cancer eye At present, the consensus is that a short, sleek or glossy hair coat over a pigmented skin that is kept soft and pliable is most appropriate for warm climates Indigenous stocks usually meet all these requirements, whereas temperate zone stocks do not.

Sweating Rate

As pointed out in Chapter 3, cattle and sheep from the tropics have more sweat glands per unit of body area than animals from the temperate zones (Nay and Hayman, 1956); it is thus assumed that they have a higher capability for sweating. This has been reasonably well documented by experiments in Australia and the U.S. But some qualifications should be noted. For instance, the data in Table 5.3 indicate that Hariana and Gir (Zebu type cattle) sweat more than Jerseys, Holsteins, or Red Sindhi crosses with these two breeds when tested under extremely high temperatures. But the Murrah buffalo, which is indigenous to warm climates, may have a rate as low or even lower than those of Jerseys and Holsteins, depending upon the season in which the measure is made. Another qualification that should be kept in mind is that the environmental conditions the animals are accustomed to prior to a stress period markedly influences their sweating rate, and thus the judgment, about this characteristic. The contrast in output between winter and the other two seasons for Hariana cattle is quite high, whereas contrast from winter to monsoon in Gir and buffaloes is nil. The Gir had no higher output when subjected to the 40°C in the monsoon season than the Jerseys in the U.S.

From the values in Table 5.3 it appears that the cattle breeds in India are 47% superior to Jerseys when sweating is stimulated to about maximum, 35% superior to Jerseys when the previous exposure has been to warm, humid conditions, but similar to Jerseys when previous exposure has been to cool conditions. Tests made in Australia revealed some superiority for the Zebu over European breeds in sweating rates (Nay and Hayman, 1956). They observed that the sweat glands of the Zebus tended to be larger (both longer and of greater diameter) than those of European breeds, and also much closer to the skin surface. In appearance the glands were sac-like, with few convolutions; whereas, those in the European breeds were rarely sac-like and quite convoluted. How much influence these characteristics have on capability of output under thermal stress is yet unknown. The Australian researchers also found that level of feeding had a significant impact on sweating rate, with well fed animals having the highest rate. There are indications of diurnal variation in output during a given day. And even the location on the body where the measure is made can markedly effect the estimate of rate (see Chapter 3).

In the face of these modifying conditions, we must exercise caution in comparing the two major types of cattle. The preponderance of the current evidence indicates that Zebus have a somewhat higher

TABLE 5 3
Evaporation rates from the skin of various breed groups when exposed to 38°–40°C temperatures

Breed Group	*Number of animals*	*Evaporation rate (mg/10cm²/5 min)*		
Jersey (J)	25	45 ± 2 7[a]		
³/₄ J–¹/₄ Red Sindhi (RS)	6	47 ± 3 0		
¹/₂ J–¹/₂ RS	20	50 ± 3 3		
¹/₄ J–³/₄ RS	7	50 ± 2 9		
Holstein (H)	12	43 ± 3 9		
¹/₂H–¹/₂ RS	7	45 ± 3 3		
		Summer[b]	*Monsoon*	*Winter*
Hariana	6	63 ± 2 4	75 ± 3 3	44 ± 1 5
Gir	6	69 ± 2 7	47 ± 1 3	45 ± 0 9
Murrah buffalo	5	51 ± 2 5	26 ± 2 2	24 ± 1 2

Source McDowell *et al.*, 1961 Joshi *et al* 1968*a*,*b*
[a] Data collected after animals were exposed to all seasons in the U S
[b] Summer monsoon, and winter describe the conditions the cattle experienced prior to being subjected to 40°C temperature Mean daily temperatures for the 3 seasons were 32° 30° and 17°C respectively

capability for sweating, but it may not be of the magnitude often assumed because maximum rate is associated with environmental conditions and, as with humans, there is a wide variation among individuals in the rate of output

The very limited observations on sheep breeds suggest that the differences in sweating rate between breeds of sheep from the tropics and those from temperate areas are about the same as those depicted for cattle, except that sheep generally have lower levels of output—e g , about 10g/m²h at 20°C and 30g/m²h at 40°C for shorn, fine wool type breeds (Brooks and Short, 1960) These rates appear less than for hairy breeds, based on the observation that fat tailed sheep in India dripped sweat when standing in the sun The evaporation rates measured on shorn sheep must not be applied unreservedly to sheep with fleece because the dynamics of water movement in the fleece, especially in fine or medium wooled sheep, are unidentified Most researchers have concluded that with full or nearly full body covering, cutaneous water loss is usually relatively unimportant compared with respiratory cooling in a warm climate

In Australia some sheep have been found congenitally lacking sweat glands How widespread the condition may be among various groups of sheep is yet undecided According to the observations in Australia, the congenitally deficient sheep did so poorly under thermal stress that the characteristic would tend to be self eliminating, at least in warm climates

Surface Area

Several writers have emphasized that animals indigenous to hot climates, particularly cattle, have a greater ratio of surface area to mass—about 12% greater—particularly between Zebu and European breeds of cattle (Kibler and Brody, 1950). This may be true under the usual conditions of observation, but largely because of differences in size between Zebu and European breeds at the time of observation. If the animals of the two groups were of similar age and weight, the contrast in area to mass ratios would probably not exist, although this hypothesis has not been tested by direct experimentation.

From the data available for Zebus, their crosses with European breeds, and pure European breeds, it has been found that the correlation of age and weight ranges from 0.85 to 0.96 in all groups. The

TABLE 5.4
Averages for body surface area of groups of cattle, unadjusted, adjusted for age effects and adjusted for weight at a constant age as heifers or cows. Within heifer groups and breed groupings in cows, i.e., Jerseys and crosses or Holsteins and crosses, values in the same column with a common superscript (1, 2, or 3) are not significantly different, but do differ from those not having the same superscript [P < .05].

Breed group	*No. animals*	*Surface area (m^2)*	*Surface area adjusted for age (m^2)*	*Area adjusted for weight at constant age (m^2)*
		HEIFERS		
Jersey	6	2.03^{1}	2.04^{1}	2.37
Brown Swiss	6	2.58^{2}	$2.59^{2,3}$	2.58
Holstein	6	2.63^{2}	$2.64^{2,3}$	2.63
Shorthorn	6	2.60^{2}	2.57^{2}	2.58
Santa Gertrudis	6	3.06^{3}	$3.05^{2,3}$	3.04
Brahma	6	3.08^{3}	3.07^{3}	3.06
		COWS		
Jerseys	34	4.30^{1}	4.25^{1}	4.17
3/4 J[a]	10	4.04^{2}	$4.10^{1,2}$	4.08
1/2 J	33	4.15^{2}	4.31^{1}	4.20
1/4 J	23	3.87^{3}	3.95^{2}	4.12
Holsteins	16	4.68^{1}	4.60	4.46
3/4 H[a]	8	4.47^{2}	4.45	4.40
1/2 H	11	4.44^{2}	4.52	4.45

Source: Data on heifers from Johnson *et al.*, 1961; on cows from Branton *et al.*, 1966.
[a]Crosses of Jersey or Holstein and Red Sindhi.

relation of age and surface area is in the same range and appears nearly similar in both groups The correlation of body weight and surface area is high for Brahman, Santa Gertrudis, Shorthorns, Holsteins, Brown Swiss, Jerseys, and crosses between Jerseys and Red Sindhis (0 95 to 0 98) This means that differences among breeds of cattle are mainly due to variability in body weight, since means of various groups showed no significant differences after adjustment to a common body weight and a constant age (Table 5 4) Still, there is a slight advantage in surface area favoring the Zebu (Brahman) or crosses with a high proportion of Zebu but not of the magnitude generally credited What this signifies is that if a Zebu and a Brown Swiss or a cow of another European breed weigh 300 kg each and are of the same age, the weight to mass ratio will be similar So, as in the case of sweating rate, we should be cautious about comparing surface to mass ratios without considering the factors that influence this relationship

Body Conformation

Due to its characteristic hump and large fold of skin underneath the neck (dewlap), the Zebu has a somewhat different body configuration than European breeds (Figure 5 4, top portion) That the appendages represent, not additional surface area, but a change in body configuration has been demonstrated by McDowell *et al* (1959), who found that body length (withers to hips) decreased 2 cm with each increase of 25% in Zebu breeding How much the Zebu body configuration has to do with its tolerance to tropical climates is unknown As indicated in Chapter 3, the appendages are not adjacent to the main sources of heat production, they have a poorer blood supply than areas of the main trunk, and their rate of evaporation is less Assessment of response to thermal stress of Red Sindhi bulls following removal of the dewlap (center portion of Figure 5 4) and amputation of the dewlap, hump, and one half the ear surface (lower portion of Figure 5 4) did not reveal that these appendages were collectively important to the bull's capability to adjust to hot conditions If ambient temperature conditions were higher than skin temperature, the body shape of the Zebu would afford advantages, but in a warm, humid climate where ambient temperature is lower than skin temperature the value of the appendages seems questionable

The value of the hump to the well being of the Zebu is not clear In the course of studying the role of the hump in resistance to thermal

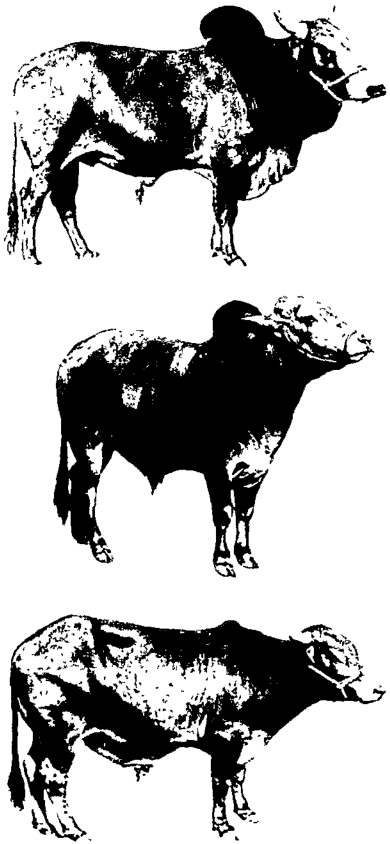


FIGURE 5.4
Red Sindhi bulls intact (top); with dewlap surgically removed (middle); and with hump and dewlap removed and ears trimmed down to the size for Jerseys. Removal or reduction of the appendages did not bring about a significant change in the response of the animals to thermal stress.

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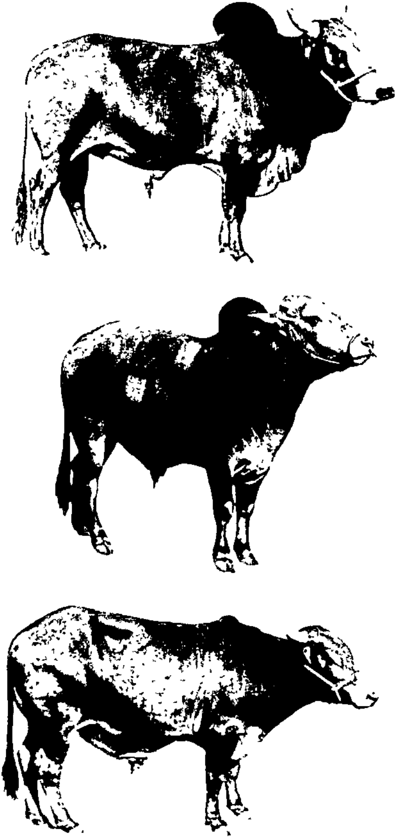

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Red Sindhi bulls intact (top); with dewlap surgically removed (middle); and with hump and dewlap removed and ears trimmed down to the size for Jerseys. Removal or reduction of the appendages did not bring about a significant change in the response of the animals to thermal stress.

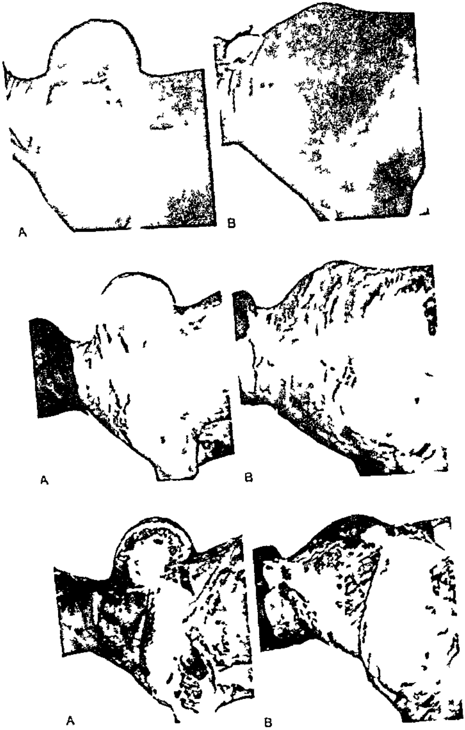

FIGURE 5.[illegible]
Red Sindhi (left) and Red Sindhi Jersey crossbred (right) males showing contrast in location of hump (top section), after removal of the hides (center section), and after removal of the trapezius muscle to expose the attachment of the romboideus (hump) muscle

FIGURE 5.6
Longitudinal section of the hump and spinal processes of Zebu bull. The hump rests on the spinal processes but is not attached; it is well marbled with fat and has an external covering of fat in proportion to the general fatness of the animal. (Courtesy Agric. Res. Service, USDA).

stress, it was found that the hump was not important in locomotion (McDowell *et al.*, 1958). In the Indian Zebu the hump is erect and directly above the center of the scapulae (Figure 5.5). It is attached to the scapular cartilage by a small segment of cervical fibers. The B portion of Figure 5.5 represents a Zebu-European cross. One-half European breeding causes the hump to lie along the neck like the crest muscle in bulls of European breeds, but total weight of the hump and its attachment to the scapular cartilage are the same as for Zebu. A longitudinal cut through the hump and spinal processes (Figure 5.6) shows that the hump is not directly attached to the spinal processes. Its insignificance in locomotion indicates the hump is not as well supplied with blood as other areas, thereby not likely significant to promoting heat loss. Perhaps attention has been given to having an

erect hump in areas where cattle are used for agriculture power, for ease in pulling rather than for an important role in thermoregulation

Apparently climatic conditions manifest to a certain degree the length of legs of animals indigenous to the area Animals inhabiting desert areas tend to have rather long legs in relation to body size—e g , the camel and the donkey Sheep and cattle from these areas have longer legs than those from temperate areas This could be a partial adaptation for reducing reflected radiation from the ground, as well as for increasing the animals' ability to cover vast areas for feeding and watering To what extent the length of leg in tropical breeds of cattle has resulted from the pressures of the environment, and to what extent length has been reduced in temperate breeds through selection can not be discerned

Maintenance of Heat Balance

Cattle and sheep indigenous to warm climates are on the whole more efficient in their use of respiratory cooling because they tend to utilize a shallow or panting type breathing rather than a deep bellows type, which increases the risk of hyperventilation (McDowell *et al* , 1955) The characteristic breathing of the indigenous stocks probably interferes less with feeding and perhaps has less influence on the appetite center Since the indigenous animals generally have less genetic potential for growth and milk yield, their demands for feed are more readily satisfied Low feed intake in turn produces less heat load, therefore, the animals' systems are not forced to function on as high a level as when feed intake is higher

The Zebu will seldom show a marked rise in body temperature Under mild to intermediate levels of stress, it will show less disfunction in performance than European breeds, but under high levels of stress its proportional reductions in growth rate, milk yield, and feed intake will equal or exceed those of European types This lends support to the theory that, as with nearly all other traits, the differences in respiration rate or body temperature are meaningless unless we know a great deal more about the environment, levels of feed intake, and performance

Metabolism and Feed Efficiency

The majority of Zebu cattle, as well as cattle native to Africa, have lower basal metabolic rates, resulting in lower maintenance require-

ments per unit of body mass. Tests in Kenya showed the local native breed, Boran, to have a 10% lower metabolic rate than Herefords. Indigenous cattle's smaller body size and smaller digestive systems per unit of body weight no doubt aid in efficiency of digestion, particularly with low levels of feeding and poor quality feeds (Rogerson *et al.*, 1968). A small digestive system probably limits appetite, in contrast to a large rumen capacity, which permits greater intake of feed in a short period. A slow, relatively constant rate of intake would tend to maintain rate of heat production in the body at nearly a constant level. Zebu cattle are inclined to slow eating even when offered liberal quantities of highly palatable feeds; and this behavior contributes to a steady, consistent rate of heat production.

Experimental evidence from Louisiana State University and the University of Missouri has shown that metabolic heat production is lower for Zebu cattle than for European breeds. In the Louisiana studies, the heat production of Red Sindhi-Holstein crossbreds was less than for Jerseys or Holsteins. The estimated ratio of heat produced per square meter of body surface for the crosses was 57% of that for Holsteins and 76% of that for Jerseys; but the heat increment per kg of milk yield was the same for all groups. These findings are supported by studies at the National Dairy Research Institute in Karnal, India, which showed that Sahiwal, Tharparkar, and Red Sindhi cows had lower levels of metabolic heat production than those reported for European breeds.

In spite of differences in metabolic rate, there is no good proof of differences in digestive efficiency between Zebu and European breeds, especially on medium to high levels of feeding (French, 1940). It seems the food is digested and utilized with equal efficiency by both types. However, when efficiency is judged according to the ratio of units of feed required per unit of product, the European breeds far excel. Trials in Kenya showed Herefords were more than twice as efficient as native Boran cattle in converting feed to live-weight gain on high levels of feeding (Rogerson *et al.*, 1968).

From the foregoing evidence, it would follow that in adverse nutritional circumstances, such as those imposed by drought, the indigenous animals would have a better chance of survival, or at least they would suffer smaller losses in body weight, whereas on high levels of feeding they would be less efficient than European breeds.

Some experiments have demonstrated that animals from tropical areas can tolerate more extensive dehydration, in which case they could go for longer periods without watering. But here again there are confounding factors. Water intake is closely related to dry matter

intake Since indigenous types have a lower dry matter intake in drylot or on grazing, the differences reported for water intake may more truly reflect a lower level of feeding than a peculiar physiological requirement for less water Although Quarterman *et al* (1957) demonstrated that the water reabsorption powers of the colon of European type cattle was less than for Zebu, no consideration was given to differences in levels of feed intake Especially with poor feeding, European cattle would be apt to take in more dry matter than indigenous cattle and consequently have greater thirst problems

Several workers, notably Howes *et al* (1963), have submitted evidence that Zebu cattle are superior to European types in their capacity to digest food because of differences in the rates of fermentation in the rumen The Zebus had higher fermentation rates, and there was some indication that they could better utilize the low protein coarse fodders that are common to the tropics The latter findings have been confirmed by research in India that showed Zebus retained more nitrogen than reported for European breeds

In a series of experiments with Hereford, Brahman, and Holstein yearling steers on a ration of 25% alfalfa hay, 44% barley, and 30% molasses, the gm/unit of metabolic size ($W^{3/4}$ kg) was 51, 41, and 40, respectively, for the three breeds The utilization of feed consumed above maintenance for energy deposition (determined from the slope of the regression of food intake/$W^{3/4}$ against energy gain) indicated that each Mcal of energy gain required 10 3, 11 8, and 14.1 gm of feed/$W^{3/4}$ kg for Herefords, Brahmans, and Holsteins, respectively These tests demonstrate that the three breeds were approximately equal in the efficiency of utilization of feed for maintenance but that the Brahmans and Holsteins were less efficient (87% and 73%, respectively) than the Herefords in converting feed energy into body energy (Garret, 1965)

Internal Anatomy

The important differences between Zebu and European breeds in metabolic heat production and internal anatomy suggest that the higher tolerance to thermal stress of the Zebu types may be due more to internal body characteristics than to efficiency in promoting heat loss Postmortems on crosses with 25, 50, and 75% Red Sindhi in combination with Jersey or Holstein, revealed important differences between the internal organs of these animals and the organs of pure Jerseys and Holsteins (Swett *et al* , 1961) The dressing percentages (24-hour shrunk live weight/empty body weight) of the crossbreds

with 50% or more Red Sindhi were significantly higher than for the pure European breeds. Since weight of hide per unit of empty body weight was similar for all groups, the major differences were due to size of the internal organs and fill of the digestive system. The omasum and abomasum of the 50 and 75% Red Sindhi crosses were 21–30% smaller than those of Jerseys, and the rumen and reticulum were 11% smaller. The total length of intestines for the crosses was 8–13% shorter than for Jerseys on a comparable body weight basis. Each 25% increase in Red Sindhi heredity reduced the diameter of the intestines by about 0.1 cm, and the weight of fill of the digestive organs was significantly less in these crosses. The sizes of liver, spleen, pancreas, pituitary, thyroid, and adrenal glands of the crosses with 75% Red Sindhi breeding were substantially smaller than in Jerseys, but these differences were not apparent in the 25 and 50% crosses. The thymus and parathyroids were not affected by the proportion of Red Sindhi breeding.

Furthermore, marked differences were observed in the subcutaneous adipose tissue. The average thickness over the 11–13 ribs was 0.8 cm for Jerseys and Holsteins, but increased consistently with greater proportions of Red Sindhi breeding up to 1.7 cm for the 75% Red Sindhi crosses. Crossing did not appear to influence the proportion of peritoneal adipose tissue. These findings suggest no pronounced difference between indigenous and European breeds in the deposition of fat. On the other hand, it has been reported that Boran cattle from East Africa store less of their total adipose subcutaneously than European type cattle (Ledger, 1959). Whether the difference in observations was due to the types of cattle or to age and fatness of the animals at the time of slaughter is unidentified. The Boran carcasses did, however, have 3–4% more fat than contemporary Herefords.

Evidence has been presented on several occasions for major differences between cattle indigenous to warm climates and European types in age of puberty, reproductive efficiency, growth rate, mature size, milk yield, susceptibility to disease, and resistance to external parasites. Differences in all these traits are no doubt related, at least indirectly, to ability to survive in extremes of climate and hence, to general suitability of animals to hot climates. Since these traits are more or less indirectly related to the physiology of heat balance, they will be dealt with in subsequent chapters on breeding and management.

A general summary of the possible advantages of indigenous cattle for warm climates is given in Table 5.5. Positive and negative values portray the deviations from European breeds in traits that might be expected to afford certain advantages for warm climates.

TABLE 55
Relative comparison of certain traits of cattle indigenous to tropical areas with those of European type cattle (–) less than European, (+) greater than European (?) unsettled (0) no pronounced difference

Trait	*Deviation from European type*
Length of hair coat	–
Thickness of skin	+
Skin pigmentation	+
Secretion from sebaceous glands	+
Body surface area in relation to unit size	?
Body size (weight and skeletal dimensions)	–
Number of sweat glands/unit of body surface	+
Sweating rate when stimulated by hot conditions	+
Length of legs in relation to total body height	+
Level of basal metabolic heat production	–
Total energy required for maintenance	–
Heat production/unit of milk energy produced	0
Efficiency of digestion at low levels of feeding	+
Efficiency of feed utilization on high feeding	–
Rate of feed intake	–
Size of digestive system	–
Size of endocrine glands	?
Size of internal organs	–
Tolerance to dehydration	+
Susceptibility to respiratory alkalosis	–
Ability to maintain normal heat balance	+
Tolerance to rise in body temperature	?
Deposition of adipose tissue	?

The advantages of individual traits, and even the nature of interaction effects, are as yet unclear But observations to date suggest that a major advantage of indigenous type cattle lies in their apparent inherent small size as compared to most of the breeds or types originating in the cooler climates At least this is strongly suggested from most of the observations made to-date There is perhaps one exception, that of the Criollo cattle found in the Lake Maracaibo region of Venezuela These cattle are somewhat larger than other indigenous cattle But how they compare to European breeds for warm climates has not been evaluated It has been noted that several of the features affording advantages for indigenous types may have more to do with internal physiological functioning than direct avenues of heat loss If this is a proper assumption, it further emphasizes the inadequacies of the indices described earlier for assessing animal suitability to warm climates

Sheep indigenous to warm climates, like cattle, seem to have some special adaptive features (MacFarlane *et al.*, 1967). Those having to do with sweating rate, metabolic heat production, digestive efficiency, tolerance to dehydration, and size of internal organs appear to show the same sorts of differences as those of indigenous cattle. The sheep found in the hot, dry regions of northern Africa and southeastern Asia are less compact in body. They have long legs and large ears in comparison to groups found in the cooler climates. They have a less compact body covering consisting either mostly of hair or of coarse wool. Many of these groups show one of three types of tails: long, broad fat tail, fat tail but intermediate in length and width, or short fat tail with fat rump, and some have deposits of adipose tissue in the neck and dewlap as well. Most of the types with these anatomical features deposit little fat subcutaneously. This should prove more beneficial under extremely hot conditions than a similar amount of fat distributed over the entire body surface.

In total number, the Merino type sheep are found most widely in the N-S 30° latitudes. There are several strains or groups that have been developed in various localities from the original Merino of southeastern Europe and north Africa. The Merino seems to have about the same position among sheep breeds as the Zebu cattle from southeast Asia. They are smaller in size than breeds found in the northern part of Europe or the U.S. They are slow maturing and have a lower inherent growth rate than many of the British mutton breeds. Their reproductive efficiency under good feeding and management is less than for the British breeds. Nevertheless, research in Australia with the Merino types developed there indicates that they are well suited to the northern territories, where seasonal temperatures are extreme and feed supplies are rather poor. Their suitability to these conditions seems to hinge on several of the same features possessed by indigenous cattle (Table 5.4).

DETERMINING ANIMAL SUITABILITY BY PRODUCTIVE FUNCTIONS

It is evident that before making decisions about the suitability of animals for the warm climates, one should know wherein lie the advantages of particular breed groups. It is also important to know how much the advantages or disadvantages of certain characteristics are worth in relation to the purpose the animals are expected to serve. In hot, dry environments the advantages of indigenous animals may range from 5 to 100%. The low advantages apply to features like

hair color, while 100% applies to size in relation to available feed supplies, as illustrated in Figure 4 5 In warm, humid climates the advantages may be somewhat less for the majority of the traits—possibly in the range of 1 to 30% over those cattle of European origin but up to 100% where feed conditions are extremely poor It should be kept in mind that these probable advantages have to be weighed against the inherent ability for performance—e g , growth rate, reproductive efficiency, milk yield, and wool production

Table 5 6 provides an illustration of how comparative evaluations ought to be looked upon in assaying which animals are most suitable to a given environment This table summarizes results of a long-time study on the feasibility of combining Red Sindhi and Brahman (two breeds of Zebu cattle) with European breeds to improve the adaptability of dairy cattle to the Gulf Coast region of the U S The merits of introducing traits from the Zebu breeds were judged by varying the proportions of Zebu breeding from 1/8 to 3/4 Each crossbred group was compared to contemporary purebred Jerseys, Holsteins or Brown Swiss A zero sign (0) in the table indicates no significant difference between crossbreds and purebreds Negative (−) and positive (+) values indicate the significant disadvantages and advantages, respectively, for the crossbred groups The traits measured were grouped into two classifications—performance and physiological adaptation

The crossbred groups with 1/2 to 3/4 Zebu breeding showed consistently greater physiological adaptation than the European-breed contemporaries, but they were lower for most performance traits The 1/8 and 1/4 crosses (fraction of European breeding) were similar to their European breed contemporaries in most respects, except for inferior yields of milk and milk fat Even though the crosses with 1/2 or more Zebu breeding tended to excel in physiological adaptability, it was concluded that the losses in performance traits did not justify attempts to select for possible higher physiological adaptability These evaluations were made in relation to conditions in the southern U S and may not be entirely valid elsewhere Nevertheless, the principles in determining suitability remain the same

A scale of assessment, such as illustrated in Table 5 6, would be desirable for development of selection programs for local stocks and determining the potential of various groups might be selected from other locations But all the effort required is too costly and time consuming to be recommended for extensive use Yet, from the foregoing discussions and those in the chapters that follow on feeding, breeding, and management, it seems there is adequate information available for general classifications on the suitability of stocks For example, Table 5 7 shows the likely rankings of various groups of cattle for

TABLE 5.6

Summary of relative comparisons of the major Sindhi and Brahman crossbred groups to purebred Jerseys, Holsteins, and Brown Swiss: 0, difference between crossbred group and respective purebred not significant; −, purebred had significant advantage; +, crossbred had significant advantage; blank, no observations made.

Item	Sindhi-Jersey				Sindhi-Holstein		Sindhi-Brown Swiss		Jersey-Brahman		
	¾J	F_1J[a]	F_2J[b]	¼J	¾H	F_1H	¾B	F_1B	⅛Br	¼Br	F_1Br
PERFORMANCE											
Growth											
Body weight	0	+	−	−	−	−	−	−	−	0	+
External body dimensions	0	−	−	−		−	−	−	0	0	+
Body surface area	0	0		0	0	0					
Internal anatomy											
Size of digestive tract	0	−		−		−					
Weight of endocrine glands	0	−		−		−					
All other organs and glands	0	−		−		−					
Reproduction											
Age at sexual maturity	0	0	0	−	0	0	0	0	0	0	0
Breeding efficiency	0	0	0	0	0	0	0	0	0	0	0
Livability	0	0	−	−	0	0	0	0	0	0	0
Production[c]											
Milk (kg)	−	−	−	−	−	−	−	−	0	−	−
Fat (%)	+	+	+	+	+	+	0	+	0	+	+
Fat (kg)	−	−	−	−	−	−	0	−	−	−	−
Persistency	−	−	−	−	−	−			0	0	0
Feed efficiency	0	−	−	−	0	−					
Temperament	0	−	−	−	0	−	0	−	0	−	−
Rate of milk letdown	0	−	−	−	−	−					−
Rate of feed consumption	−	−	−	−	−	−					
PHYSIOLOGICAL ADAPTATION											
Resistance to parasites	0	+	+	+	+						
Lenth of hair coat	0	+	+	+	0	+	0	+			
Response to heat stress											
Rise in rectal temperature	0	+	+	+	0	+	0	+			
Rise in respiration rate	0	+	+	+	0	+	+	+			
Rise in respiration volume	0	+	+	+	0	+					
Decrease in tidal volume	0	+	+	+	0	+					
Metabolic heat production	0	+				+					
Surface evaporation	0	0		0		0					

Source: Adapted from Branton et al., 1966.

[a] First generation ½ Jersey–½ Sindhi crosses.

[b] Second generation ½ Jersey–½ Sindhi crosses.

[c] First lactation.

TABLE 5 7
Ranking from high to low of certain groups of cattle for characteristics indicative of suitability to hot environments under either advantageous or disadvantageous management conditions Breed groups in the same column with a common superscript (1 or 2) are not significantly different, but do differ from those not having the same superscript [P < 05]

Methods of Measuring Adaptation		
Rise in Body Temperature	*Growth Rate*	*Milk Yield*
ENVIRONMENT A ADEQUATE NUTRITION NO SERIOUS DISEASE PROBLEMS, GOOD MANAGEMENT[a]		
Zebu	Brown Swiss	Holstein
Zebu European X	Charolais	Brown Swiss
Santa Gertrudis	Holstein	Jersey
Brown Swiss[1]	Zebu X[1]	Zebu X[1]
Jersey[1]	Santa Gertrudis[1]	Zebu[2]
Charolais[1]	Hereford[1]	
Angus[1]	Angus[1]	
Hereford[1]	Jersey[1]	
Holstein[1]	Zebu[1]	
ENVIRONMENT B LOW NUTRITION DISEASE PROBLEMS POOR MANAGEMENT[b]		
Zebu X	Zebu X	Zebu X
Zebu	Zebu	Jersey
Brown Swiss[1]	Brown Swiss[1]	Brown Swiss[1]
Jersey[1]	Hereford[1]	Holstein[1]
Angus[1]	Charolais[1]	Zebu[2]
Charolais[2]	Holstein[1]	
Holstein[2]	Jersey[1]	
Hereford[2]	Angus[1]	

[a] Assumes ample quantity and quality of feed throughout the year good disease control measures, and experienced personnel for management.
[b] Assumes poor quality feed with serious seasonal fluctuations, little effort made to control disease, and inexperienced personnel

suitability to warm climates where certain general environmental conditions prevail and either displacement of body heat balance or performance are used as criteria If the conditions for environment "A" are met and body temperature is used as the scale, the Zebu breeds would look the most suitable, followed closely by Zebu-European crosses of 50% of each type, and Santa Gertrudis, a breed with about 40% Zebu The crosses would not be significantly different from the pure Zebu, but they would be significantly better than the representatives of the European types listed On the other hand if in the same environment suitability is determined solely as

growth rate or milk yield, the rankings would be quite different (Table 5.7). In general, the European types would be superior to the Zebu or Zebu-European crosses, even though the European breeds would be performing at less than optimum efficiency.

Under environment "B" conditions, rankings based on the least displacement or rise in body temperature would place the breed groups in about the same general order as in environment "A" with the exception of significant separations in the European types. But the rank order for growth rate and milk yield would be quite different from those in "A." Based on current research findings, rough evaluations of suitability could be made after development of an environmental profile (see Chapter 2).

Another fairly crude but effective basis for choosing breed groups might be mature size (small, medium, or large) in relation to the extremes of climate, since this has a direct relation to available feed supplies (Table 5.8), very limited 2–4 months rain, moderate 5–7 months rain and reasonably good 7–10 months rain. Where the feed supplies are very limited as in an environment with a rainy season of 2–4½ months, small indigenous cattle breeds or sheep or goats would be most practical unless irrigation or supplementary feeding could be used extensively to enhance feed supplies. In the 5–7 month rain areas the medium or intermediate size breeds would likely be most satisfactory from the standpoint of performance (Table 5.8). The use of large breeds in warm climates is justified only where there are ample supplies of feed of good to excellent quality, effective measures of disease control, and some protection provided against the extremes of climate. This could be accomplished in 7–10 month rainfall areas at the least cost.

If in a given locality the ration is likely to consist of coarse feeds such as straw and grass of low to medium quality, with little or no concentrates, the total energy supply available to the animal would most likely be less than 3000 Mcal per year. With such feeding the small cow, even though potentially a low milk producer, would probably yield as much or more than a cow from a large breed because the total feed supply would not meet even the maintenance requirements for the large cow. In contrast, the small cow's maintenance requirements would be about 2000 Mcal per annum, thereby leaving some energy from the feed supplies for productive processes. The capability of the large animal would be further inhibited because the underfeeding would reduce its resistance to disease and parasitism.

Still another system for determining suitability of cattle to tropical climates could be based on the potential of the land, the cost of the land, and the potential for capital investment. For example, for

TABLE 5 8
Examples of recommended breeds of cattle most suitable for dry wet dry and humid summer environments

Dry (2–4 months rain)	*Wet Dry* (5–7 months rain)	*Humid summer* (7–10 months rain)
Small breeds 250–400 kg	*Medium breeds 400–500 kg*	*Large breeds >500 kg*
Zebu	Boran	Charolais
N Dama	Zebu X	Holstein
Criollo	Africander	Brown Swiss
	Angus	Santa Gertrudis
	Jersey	Hereford
		Shorthorn

operations involving continuously stabled cattle (principally near sizable urban centers) the use of high grade or European breeds of cattle, both for beef and dairy operations, could be recommended, for stabling and pasturing in combination, improved crossbred types, and for continuous pasturing on native grasslands, indigenous types or first generation crosses of European and Zebu breeds Such classifications would be closely related to the intensity of operations, that is the inputs per animal

Strong arguments could be put forth to support the need for considering numerous other variables in determining the suitability of animals for a given environment, such as resistance to ecto-parasites The problem is that there is no simple method that can be used to determine which animals will perform most satisfactorily in a given environment. All breeds known today and their crosses have certain strengths and weaknesses From the practical standpoint, we ought to be flexible about choice of animals, mainly because environmental conditions are subject to change For instance, in an area that is initially isolated because of inadequate transportation, emphasis must go toward making the best use of local resources If a roadway were to be put through the same area, additional inputs would probably pay, but in order for these to give satisfactory returns on investment a somewhat different type of animal would no doubt be required

The animal geneticist would readily argue against broad latitude in systems of breeding because this would restrict the opportunity for selection within one breed group for suitability to a given environment This point cannot be refuted directly But this rigidity in attitude about breeds and breeding systems must change if livestock

enterprises are to become economically profitable in warm climates. This issue will be dealt with more extensively in chapters on breeding and management.

Although most of the examples cited in this chapter for judging suitability on performance and size were for cattle, the principles should be largely applicable to other species of livestock.

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III

FEED SUPPLIES

6

Problems of Forage Production in the Warm Climates

In spite of what has been said in the previous three chapters about the deleterious effects of warm climates on the comfort and efficiency in the performance of livestock, inadequate nutrition constitutes the major inhibitor to higher outputs of livestock products. The causes for poor feeding are numerous; some created by man—e.g., destruction of grasslands through overgrazing—and others by nature—e.g., rainfall distribution. Although man and the environment in warm climates create handicaps, there are numerous favorable signs that feed supplies could be expanded, either through improvement of grazing lands or better use of products already available. This chapter and the following chapter deal with feed supplies from forages and other products used to replace or augment forages.

ENVIRONMENTAL PROBLEMS

Currently it is estimated there are 1.5 billion hectares of land under cultivation, with about 60% actually harvested annually. In Table 6.1, the land designated as potentially arable is defined as land with no physical limitations that would prevent cultivation employing

TABLE 6 1
World land resources in relation to climatic factors limiting food production (million hectares)

Limitations	Potentially arable	Non arable		Total
		Grazing	Other	
Temperature	820	940	2950	4710
Moisture	1300	1500	1360	4130
Moisture and temperature	550	920	1640	3110
Not limited by temperature or moisture	500	330	360	1190
Total	3170	3690	6310	13140

Source FAO data

present day modern machinery and technology The non-arable portion is that which has physical limitations inhibiting cultivation, such as steep slopes or outcropping rocks The N-S 30° area has about 50% of the potentially arable land and approximately 52% of the non-arable land by present day standards The non-arable grazing refers to permanent or nearly permanent grasslands These include a wide array of types from desert grasses and shrubs to tall prairie grasses—all products of natural forces, plus former use that favors grass and small plant growth rather than trees The other non-arable lands are those which currently have little or no use for agriculture, such as the truly arid areas Although the lands of much of the N-S 30° area have physical limitations, it seems that much of the land could contribute more to feed supplies for livestock than now

Rainfall Distribution

Although rainfall and temperature were discussed in Chapter 2, further examination of their patterns of variation is necessary to appreciate their importance in relation to feed supplies To the livestockman the average annual rainfall is perhaps less important than the variations encountered within a given season and year to year The rate of growth and nutritive value of natural forages, especially in the grasslands regions, are direct reflections of the amount and distribution of rainfall, therefore, rainfall is one of the more critical factors in determining the potential for animal production

The tropics include 30–40% of the approximately 13 5 billion hectares of land in the world There are five classifications of land in the tropics based on characteristic rainfall patterns (Table 6 2) The

TABLE 6.2
Land areas of the tropics (million hectares) classified by characteristic rainfall distribution. Humid months are those with at least 8 cm precipitation.

Regions	Asia & Pacific Islands	Africa	Oceania	South America	North America	Total
Rainy (9½–12 months humid)	350	200		600	450	1600
Humid summer (7–9½ months humid)	270	500	10	580	50	1410
Wet–dry (4½–7 months humid)	150	640	50	100	80	1020
Dry (2–4½ months humid)	90	490	110	70	20	780
Semi-desert and desert (2 months humid)	130	300	100	20	10	560
Total	990	2130	270	1370	610	— 5370

Source: Adapted from Landsberg *et al.*, 1963.

high rainfall area represents 24% of the lands; humid summer, about 28%; wet-dry, 21%; dry 16%; semi-desert and desert, about 11%. It is evident from these rainfall patterns that most of the area in the N-S 30° latitudes must have definite fluctuations in plant growth.

Even in the wet regions where rainfall may be rather uniformly distributed throughout the year, usually the interaction of temperature and rainfall produces at least two distinct periods of variation in the quantity and quality of feed supplies. The island of Singapore, for instance, which lies astride the equator, has a high level of rainfall uniformly distributed; yet very careful management is required to even approach a consistent supply of quality forages. Unless the grasses are cut at short intervals (<45 days), they will mature rapidly, resulting in decreased palatability and digestibility, just as in areas with distinct wet and dry seasons. Thus, in the natural or the unmanaged state the feed supplies of the tropic and subtropic grasslands are insufficient in both quantity and quality for profitable livestock enterprises.

The characteristics of the soil are important in the availability of soil moisture for utilization by plants. In both the wet-dry and rainy climate regions much of the soil tends to develop almost impermeable layers on or near the surface, thereby lowering water storage during the rainy season and promoting consequent rapid deterioration in the quality of the grasses with the onset of the dry season.

Temperature and Moisture

Although no detailed studies have been made of temperature limitations in the N-S 30° latitudes, certain implications can be derived from the FAO data in Table 6 2 In about 36% of all lands, production is limited by temperature, by moisture in 31%, and by both moisture and temperature in 24% Only 9% of the world's total land area seems to have no defined limitations of moisture or temperature Assuming that about 40% of the total land area is in the low latitudes, there are bound to be limitations due to temperature Coupled with this are the influences of topography and wind patterns on seasonal temperatures Therefore, the portion of the N-S 30° area that does not have some restrictions of temperature that would influence feed supplies is relatively small and certainly much less than the usual temperate zone inhabitant's concept about warm climate areas When moisture limitations are combined with temperature, the area without definite restrictions is very small

Soil Characteristics

Another limiting factor in food production for livestock is the quality of the soils Table 6 3 shows the extent of different types of soil in each of the major rainfall distribution areas of the tropics The soils that are rich in bases are usually low in nitrogen but have enough of most of the other elements for adequate fertility The leached, acid soils are deficient in minerals in the upper layers and hence are not well suited to current methods of cultivation The shallow soils have problems similar to those of the leached soils, plus lack of depth The alluvial soils occur in the flood plains of the rivers, where the surface is usually renewed annually by flooding The potential productivity of these lands is reasonably good providing flooding can be stopped and suitable drainage developed Such inputs are, of course, costly—ranging from about 400–4000 U S dollars per hectare, depending on the width and length of the drainage canals required To justify the high costs of drainage, irrigation is often recommended The high fertility of these soils may make such an undertaking feasible Experiments on drained land in northern Colombia, which has 30-50% alluvial soils, have shown no significant response to nitrogen applications with corn for up to 12 years, indicating a high potential for agriculture production without nitrogen fertilizer

Of the 5 1 billion hectares in the tropics (Table 6 3), over 70%

TABLE 6.3
Classification of tropical land areas by rainfall distribution and soil characteristics (million hectares).

Desert, semi-desert and dry climates	1330
Soils rich in bases	680
Leached soils	130
Shallow soils	490
Alluvial soils	30
Wet-dry climates (4½–7 months humid)	1020
Soils rich in bases	220
Leached soils	560
Shallow soils	170
Alluvial soils	70
Humid summer climates (7–9½ months humid)	1410
Soils rich in bases	60
Leached soils	1120
Shallow soils	100
Alluvial soils	120
Rainy climates (9½–12 months humid)	1190
Soils rich in bases	30
Leached soils	930
Shallow soils	80
Alluvial soils	150
Total	4950
Soils rich in bases	990
Leached soils	2750
Shallow soils	840
Alluvial soils	370

Source: FAO data

falls under the classifications of leached and shallow soils. This means inputs of fertilizer are required to enhance the productivity of the major portion of the soils in the warm climates.

Local Population

In addition to climate and soil, and their interactions for providing feed supplies, population density may often dictate the approach undertaken. In Africa, Oceania, and South America, additional lands will be available for cultivation for some time to come (Table 6.4).

TABLE 6 4
Population (1965) in relation to current land use

Continent	Population (million)	Land (million hectares) Total	Potentially arable	Cultivated	Hectares cultivated land/person	Percent arable cultivated
Africa	310	3020	730	160	05	22
Asia	1 855	2740	630	520	03	83
Oceania	14	820	150	20	12	2
Europe	445	480	170	150	04	88
North America	255	2110	470	240	09	51
South America	197	1750	680	80	04	11
USSR	234	2230	360	230	10	64
Total	3 310	13 150	3190	1400	04	44

Source FAO data

But in Asia and Europe, the expansion of agriculture production must come largely from expanded yields on lands already under cultivation

Traditional uses of lands, transportation, and inadequacy of capital can also limit seriously planning feed resources for livestock In areas where certain lands are considered communal property, such as India, the attitude toward management of these resources oppose procedures that would enhance their contribution Usually the com munity has no provision in its organizational structure to regulate stocking rate, thus the lands become overgrazed and eventually denuded of vegetation Estimates made by FAO show that in the area extending from Egypt east to India, agricultural productivity is lost from 7–10 million hectares annually These lands are so overgrazed that the grasses completely disappear because the nomadic people insist on following the same routes in their annual migration The sedentary cultivator may be equally wedded to the past, as he may insist on continuing the production of a crop like sugarcane long after fertility is marginal and efficiency of production in other areas has left no economic incentive

The limitations imposed on an area by distance and communication with markets and absence of credit institutions are for the most part readily evident. The local populace is usually very much aware of these restrictions, whereas those due to climate, soil, and culture are not always recognized

GRASSLANDS

Two types of grasslands are generally recognized—sown and natural. The sown are those established by man from seeds, stolons, budded shoots, or any part that roots to produce new plants. The natural grasslands are those produced largely by natural forces; they include a wide array of grass types ranging from desert grass and shrub combinations to tall prairie grasses. Native or natural grasslands are currently the major resource of a large segment of the N-S 30° latitudes. Within the coming decades some of these may be replaced by sown pastures while others, for one reason or another will remain intact. So recognition of the characteristics of existing natural grasslands will continue to be important to livestockmen.

Davies and Skidmore (1966) have classified the natural vegetation by four rainfall zones: humid, subhumid, semi-arid, and arid. These broad groupings are of limited value, however, in classifying vegetation for ruminants. Besides the value of grasslands cannot really be deduced from climatic data without also considering soils and changes made by man in the local ecology. Barnard (1964) points out that of all organisms affecting development and maintenance of grasslands, man has had the greatest influence—both directly, through burning to destroy species, and indirectly, through the management of animals.

From the livestockman's point of view, the acceptability or palatability, the consumption, the digestibility, the protein and mineral content, and the seasonal fluctuations in these variables are the primary criteria for judging vegetation. Roseveare's two classification systems for Latin American grasslands (1948) appear somewhat more descriptive for estimations of animal use. In the first, she notes four types: (1) good natural grassland, having good herbage without extremes in quality due to season; (2) cool mountain grasslands usable largely in summer; (3) more or less arid grazings found in both hot and cold climates; and (4) savannas of hot climates that are subject alternately to dry and wet seasons. Her second system is based largely on the texture of the grasses. The first type includes tender or soft grasses that have flat, narrow, flaccid, succulent leaves. These types grow in fertile, moist soils or on tilled land. Some examples from Latin America are Pangola grass (*Digitaria decumbens*) at low elevations and perennial rye grass (*Lolium perenne*) in the cooler, higher altitudes. The second type is strong grasses, which are usually perennials having strong root systems and narrow, flat, subconvolute leaves. They are adapted to intermediate ecological conditions, that is neither very

moist nor very dry Among the examples given are *Tridens braziliansis* and *Paspalm fasiculatum* The third type is hard grasses, which have leaves so hard that animal grazing is limited They are usually also high in silica, which may impose further limitations for grazing These include *Stripa trihotoma* and *Sporobulus indicus*

Somewhat more understandable for the livestockman are the 5 zone groupings prepared by Bisschop and Groenewald (1963) from the data of DuToit *et al* (1940) for grasslands of South Africa, based on summer rainfall These were (1) high rainfall which produced open grassland pastures (Region 1), (2) lower rainfall, mixed grassland and shrub pastures resulting from lower rainfall (Region 2), (3) subtropical thorntree and grassland pastures (Region 3), (4) Karooshrub pastures (Region 4), and (5) desert grassland pastures (Region 5) The estimated percentages of land in each zone were 35, 22, 4, 27, and 12%, respectively Estimates of intake by grazing cattle based on samples taken at monthly intervals from each zone for two years revealed that all South African pastures composed mainly or totally of natural grasses were deficient in crude protein and phosphorus sufficient to meet the needs of grazing cattle (Table 6 5) for 5 to 9 months of the year Estimated intakes of sodium were also below animal needs most of the time Although the Karoo shrub and desert grasslands are considered the least palatable for grazing, they provided adequate levels of protein and phosphorus more frequently than did the grazing in the higher rainfall areas

Whyte (1968) puts forth the hypothesis that there is a zone, stretching from western Africa through southern Asia to Malaysia and also northern Australia, that has numerous similarities throughout—e g , monsoon climate, vegetation, and characteristic farms, land use, cropping and animal husbandry practices He contends that from the animal husbandry point of view these grasslands are somewhat of a snare and delusion with practically no potential for the production of milk Low nutritive value, coarseness, which will limit animal intake, and rapid maturity all work against economical dairy production Their main use lies in the less intensive animal husbandry in the forms of beef and mutton production

Norman (1963) described the natural grassland pastures of northern Australia as (1) protein insufficient to maintain live weight from 1–2 months after the end of the wet season, (2) phosphorus deficient practically all year, but especially so during the dry season, and (3) energy deficient. In the latter, the values of standing dry feed were moderate through the dry season, but once storm rains fell the energy value was largely destroyed by periodic wetting It was concluded

TABLE 6.5
The estimated intakes of crude protein and phosphorus by grazing cattle (approximately 300 kg live weight) from the natural pastures in 5 regions of the Republic of South Africa. Values in boldface considered as adequate for needs of animals, all others are less than adequate.

	Pasture regions									
	1	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
Month	*Crude protein (g/day)*					*Phosphorus (g/day)*				
J	567	623	584	721	486	9.6	10.3	11.8	13.6	7.4
F	492	612	598	575	457	8.8	9.9	11.5	12.1	8.0
M	451	538	533	621	504	8.0	8.6	10.5	12.2	7.3
A	441	479	504	639	537	8.0	7.9	9.2	12.8	7.6
M	359	406	445	613	639	6.7	6.0	9.2	11.5	9.6
J	332	387	409	596	664	6.2	5.6	8.9	10.5	9.5
J	331	387	358	648	646	5.7	5.6	8.1	12.3	9.6
A	295	307	314	604	657	5.3	4.4	7.7	11.7	10.8
S	408	360	336	600	653	6.1	4.0	5.8	10.4	10.8
O	455	421	380	562	548	7.5	6.5	6.8	10.8	9.9
N	606	645	760	712	537	9.3	8.4	13.8	11.8	6.7
D	637	699	760	699	599	10.6	10.4	13.4	12.7	8.4

Source: Adapted from Bisschop and Groenewald, 1963

that net annual live weight gains of cattle on this type of native pasture all year round would be 50–70 kg per head. On such grazing, steers would not be likely to reach mature weight until 5 years of age or later.

The findings of nearly all writers are in agreement with the results cited from South Africa and Australia. In general, the natural grasslands of the humid, subhumid, and semi-arid areas in Australia, Asia, Africa, and Latin America consist principally of bunch-type grasses, with some fine-stemmed grasses but few, if any, legumes to aid in maintaining soil fertility and enhance the protein level of the grazing. The utilization of natural grasslands is determined by the seasonal distribution of herbage caused by moisture availability and soil fertility.

NUTRITIVE VALUE OF TROPICAL FORAGES

Most of our knowledge of the variables influencing quality of herbage is derived from temperature zone research. Many inferences in regard

to the value of tropical forages have been based on proximate analysis (usually crude fiber and protein) Judgment of quality as estimated total digestible nutrients (TDN) are then based on tables of composition and digestibility such as those devised by Schneider (1947) or Morrison (1961) Due to the shortage of digestibility data on tropical species, temperate zone data is often used in the tropics

Over the last 20 years much research on temperate forages has led to the development of chemical methods that recognize the principal factors in herbage that control and limit nutritive value This research has shown the inadequacy of crude fiber (CF) as a valid forage fraction, and also the limitations of crude protein as an indicator of energy value of feeds For example, in about 30% of the forages in Morrison's tables CF is more digestible than the nitrogen free extract (NFE), which is supposed to represent the available carbohydrates (Crampton, 1938) The abnormal estimates of CF results from extraction by sodium hydroxide of lignin and hemicellulose of forage into NFE in the CF preparation (Nordfeldt *et al*, 1949) Another error results from the analysis of the fecal collection from digestion trials, where in digestible residues from bacteria and metabolic excretions also contribute to NFE Since lignin and hemicellulose are the least digestible portions of the forage, the net result is a gross underestimate of the digestibility of the soluble fractions (NFE), while its amount in forages is grossly overestimated A much broader use of the newer techniques are required before we can make successful predictions of the utility of tropical forages for animal use

In temperate forages the CF content varies little with age, whereas there is a direct correlation between age and CF in tropical forages Therefore, most of the time the fiber content of tropical grasses is higher than that of temperate forages, while digestibility is less when compared at the same fiber level Furthermore, CF seems to be poorly correlated with nutritive value and maturity of the forage (Butterworth and Diaz, 1970)

As physiological maturity of the plant proceeds, the leaf stem ratio widens and nutritive value declines particularly in the bunch type grasses Protein, minerals, rate of intake and digestibility decline progressively, and fibrous cell wall components and lignin tend to rise At all stages the tropical forages frequently provide substandard needs of phosphorus for ruminants The improved grasses used in tropical areas may, at very lush stages, have digestive coefficients for ruminants equal to those of the best temperate zone grasses (>60%), but most are in the range 40–60% as opposed to 55–75% for temperate zone grasses

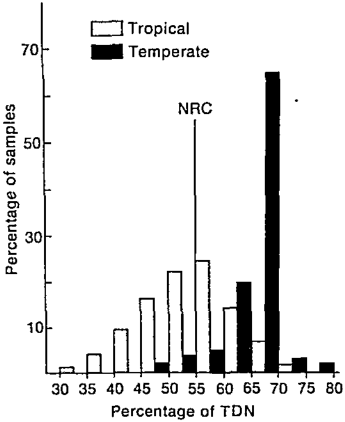

FIGURE 6.1
Variation in TDN content of some warm climate and temperate zone grasses. (NCR-National Research Council recommended minimum % TDN for growth and milk production).

The variation in percent TDN for some warm climate and temperate zone grasses is illustrated in Figure 6.1. Of the 312 samples of warm climate grasses, 52% were below the minimum level of TDN (55%) recommended by the National Research Council as needed for the growth of heifers and steers of more than 200 kg. In contrast, only 4% of the 760 samples of 13 temperate zone grasses, covering all stages of growth, had TDN values of less than 55%. The average estimated percent TDN for the temperate zone grasses in the early stages of growth was 68.7%, at time of bloom 63.8%, and at maturity or seed stage 54.2%. This indicates that most temperate zone grasses will contain the minimum level of TDN recommended except at the very late stages of maturity. The percent TDN for warm climate grasses in the early stages of growth averaged 58.1% but at 60–90 days growth the mean was 45.2% with some going as low as 28% TDN.

The characteristic growth and development pattern for most tropical grasses, including the rapid rise in lignin content with advancing age and the decline in digestibility as maturity approaches

makes it difficult to supply consistently high quality materials for grazing animals Marked seasonal changes in rainfall distribution further complicate the problems of practical farm management Seasons of high rainfall create special problems Herbage may be abundant during the rainy season as new shoots or seedlings develop rapidly The young plant is reasonably nutritious and readily consumed, but the dry matter content may be so low (<20%) that animal utilization, as measured by weight gains, will be poor Both ruminants and nonruminants grazing or fed green cut material from this type of herbage may lose weight the first few weeks It is thought that the loss in weight is a result of very low dry matter content of the forage, although bulk is probably the real factor which is an indirect effect of the water content

The principal substances determining the nutritive value of forages are protein, soluble nitrogenous substances, soluble carbohydrates including starch and pectin, organic acids, and the leaf lipids —all of which are completely available and digestible Also important are lignin, cellulose, hemicellulose, and silica, which are part of the plant cell wall Lignin is the primary factor causing the decline in digestibility High environmental temperature promotes lignification and depresses water soluble carbohydrates and also plant cell wall slightly—the latter a compensatory effect

The crude protein content of the young herbage may be as high as 14–16%, which is satisfactory for the needs of cattle 200 kg or larger and sheep or goats over 30 kg's but in the mature grasses, protein content may decline to 3% or less This level is suboptimal for reasonably good performance in all animals Research with grasses in the temperate zone suggests that bacterial activity in the rumen may be depressed if crude protein is below 8 5% Others suggest a break point of 6 0% The general consensus is that intake of tropical grasses may decline markedly when the crude protein percentage goes below 7% (DuToit *et al* , 1940) Thus, the low feeding value of many mature tropical grasses is due to restricted consumption imposed by suboptimum nitrogen for the rumen flora Improvement in animal performance when grazing such forage, especially in the dry season, requires an increase in the amount of feed ingested This does not transpire since available soil moisture limits plant growth Thus substitute feed supplies or other management practices should be employed to maintain continued performance by animals

Nitrogen fertilization will increase the protein content of the forages and yields markedly While the limiting factor of protein and available feed may be overcome, nitrogen fertilization does not produce a forage of higher digestibility

During the dry season a further decrease in digestibility of grasses may occur as a result of removal of soluble minerals, energy, and protein constituents from respiration to storage in the roots or loss by leaching and microbial fermenting. This leads to low intakes and digestibilities, and consequently losses in weight by grazing animals.

It must be emphasized that there is great variation in digestibility of even the same species from region to region. Such differences occur not only because of climate and management, but also because of soil differences, particularly in available silicon, which affects digestibility. Some preliminary observations indicate a range as large as 12% in the apparent digestibility of the dry matter of Pangola grass from three soil types (range 44–56% for whole plant) and a range of about 6% in the digestibility of young leaves (59–65%).

Little forage conservation is practiced in the tropics; and while such conservation could provide feed for time of drought and other periods of feed shortage, certain limitations peculiar to the forage and environment should be pointed out. Haymaking may be practical in the drier regions of the tropics; but in most of the tropics forage ought to be harvested at times of high rainfall, when it has a high nutritive value, thus, the making of silage may be required as tropical forage material declines in value with great rapidity. The relatively greater bulk, high proportion of cell wall substances, and low soluble carbohydrate content of tropical forage make it difficult to ensile such forage without spoilage. In a hot environment, protection from solar heat and air is essential to prevent molding and heat damage. The ratio of soluble carbohydrate to protein is also critical. Since tropical forages are lower in soluble carbohydrate, as they are when grown with high nitrogen fertilization, fermentation tends toward putrefaction. Thus management of ensilage requires greater attention in the tropics than in temperate regions.

Despite the known problems in preserving forage, little research has been done to develop a suitable technology. The great danger is that of applying temperate zone technology without regard for the special problems of the region. The result is often failure, which poisons the tropical farmer against further innovation.

POTENTIALS FOR FORAGE PRODUCTION

The natural grasslands of the warm climates presently provide poor grazing for ruminants (see Figures 1.3 and 1.4). However, as already indicated, these grasslands must continue to be utilized. Some view

the lush vegetation in warm climates as a sign of vast potential for livestock development. But others look upon the verdant growth as an illusion and believe that all one can do is continue the existing methods of allowing animals to rove over large areas of natural grass lands or, on small farms, continue the rotational system—e.g., grow a crop or two, abandon the area, and then return several years later after nature has restored some fertility to the soil. Most agree that rotational grazing on large areas in the humid tropics is difficult to apply and of doubtful merit. Between these extremes of optimism and pessimism is the realistic view that potential for improvement exists if several qualifying factors are taken into account—notably climate, soil, species, and economics which will be the final governing factor in any situation.

From the standpoint of livestock production, pastures and forages per se are of no value unless they can be utilized effectively by animals. This is a contributing factor to the optimism of some agronomists. Vast yields of forages have been reported but have not been tested through animal use. Most improved grasses have been characterized by agronomic studies, such as yields and persistence, and short term trials used for estimating animal performance but oftentimes the duration of the evaluations have been too restricted for practical use. Researchers involved in animal production have been equally inadequate on two counts, either restricted evaluations or on the opposite end, little or no inputs besides placing animals on grass for an extended period and measuring performance essentially without applying managerial skills.

Whyte (1962) has contended that it would be uneconomical to spread limited inputs of fertilizer or improved seed varieties over large areas of grassland. He notes that the tall, rank growing grasses of the tropical latitudes are not true grazing grasses inasmuch as livestock can utilize only a small portion of the herbage before it become overmature and unpalatable. And due to their characteristic growth patterns these grasses make poor mixtures with legumes, which are needed for balanced diets. The quality of the tall grasses is also closel related to the length of the dry seasons. Hence scattered fertilization and seeding would not be likely to bring about much overall improvement. Whyte recommends a system of ecological management fo broad scale improvement and the concentration of limited resource on selected small areas. In support of this recommendation, Whyt reminds us that human population pressures are so great that, wher crops can be grown, no thought can be given to establishing gras leys of several years' duration.

Researchers in Puerto Rico (Vicente-Chandler *et al.*, 1964) have advocated a complete system of intensive management practices for various crops and soils as essential for the full use of natural resources in the humid tropical areas. They admit that some tropical soils harden and become permanently unproductive if primitive cultivation is practiced. Also organic matter is important and can quickly be lost, nevertheless, high yields may be obtained if proper fertilization and soil management are applied. They argue that lack of natural fertility is not peculiar to tropical grasslands, nor need it necessarily deter development since modern agriculture does not depend upon a soil's natural fertility. On the other hand, forage specialists and some animal production experts in Australia contend that while the recommendations made by Puerto Rico researchers may be suitable for a small island and limited areas elsewhere, the high costs of fertilizer will not yield economic returns for large areas with restricted rainfall (80cm or less). In these areas, improvements in fertility and forage yields may best be obtained with legume-grass stands. They do concur with the Puerto Rico group in the belief that tropical pastures, adequately fertilized, may allow stocking rates and production as high as those of similarly fertilized temperate grass pastures (Mears *et al.*, 1966).

Payne (1969) reported an average of 773 days of grazing per hectare with improved grasses (Para, Guinea, and Napier) in the Philippines, and up to 3125 kg milk per hectare per annum, which is equal to that obtained in the temperate zones. Using milk yields of grazing cows as an estimate of the nutritive value of pastures in Kenya, Glover and Dougall (1961) concluded that their pastures were similar to those described by Payne and good enough to supply nutrients for milk production. However, they recognized that Kenya pastures might be satisfactory for shorter periods of time due to more rapid maturation of the plants in the summer months.

Upon examination of much of the published data on consumption and digestibility of fresh tropical herbage, Hardison (1966) was somewhat less optimistic. He concluded that if the tropical grasses were grazed rotationally at intervals of 20–30 days (and if the ability of the animal to graze selectively were ignored), most of the grasses examined would supply only enough digestible crude protein for maintenance and production of about 10 kg of milk per day. However, researchers in Australia have claimed that milk production from tropical portions of that country was 60% higher than the potential predicted by Hardison. The Australians also found that energy supplements in the form of concentrates increased production, although not

to the extent expected on the basis of the energy supplied by the supplement Their explanation was either that the animals cut back on forage intake when offered supplement or that they were getting less energy from the forages than predicted by laboratory analyses

Many more illustrations could be cited, but almost all studies indicate a reasonable degree of potential for forage development in tropical areas The greatest criticism at this time is the lack of knowledge about the suitability of forage species for various environments, the paucity of improved species, insufficient information on the long-time usefulness of species, and the factors that may limit the usefulness of species, such as lignin content In other words, much more research is necessary Nevertheless, the consensus of most researchers engaged in livestock development in tropical areas is that the wet tropics have vast potential for agricultural productivity, particularly animal production with ruminants, but a great deal of capital and managerial investment will be required before such areas are made productive

IMPROVING THE PRODUCTIVITY OF GRASSLANDS

Historically, grasslands have received less attention than cultivated crops While yields of grain crops have increased three- to five-fold in southeast Asia for example (as a result of the use of improved varieties of wheat, rice, and corn, fertilizer, and weed control measures), the average yields of forages have increased only slightly Yet forages continue to supply three fourths or more of all feed units consumed by livestock in many areas Increased demand for grain crops for direct human consumption will further increase the dependence of much of the livestock industry on grassland crops

There are over 3000 grasses and at least 1000 legumes native to the N-S 30° latitudes that might be useful as forage, either in their present form or in an improved form To date only a limited number of grasses and very few of the legumes have been evaluated for their usefulness with ruminants

Improvements in forage production can be achieved in several ways (1) Management may be improved—e g , by adjusting stocking rate, possibly limiting the time of grazing and allowing complete rest for one or more seasons to strengthen the stand before reintroducing stock. (2) Existing stands may be replaced with improved varieties, either by tilling and establishing a new stand or by spot replacement through sprigging or surface seeding in hopes that the new variety will eventually replace the existing stand (3) The existing stand may

be fertilized. (4) Legume grass combinations may be used to enhance soil fertility, total productivity, and the quality of the forage. (This is a very important consideration and will be treated in a separate section below). (5) Improvement in both quality and quantity of forage may be attained by treating the perennial forage as a crop to be harvested at its peak quality and stored as hay or silage.

In considering means of improving forage production, it should be kept in mind that high yields of forage per unit of land can be attained only through the use of all required practices properly executed with regard to their interrelationships. For instance, it would be unwise to fertilize pastures heavily and then not utilize them fully by grazing inefficiently or by using animals heavily infested with internal parasites. Conversely, to use good animals and intensive grazing practices on low-yielding pastures would be poor economics. It would also be wasteful to make heavy applications of fertilizer if there were little moisture or to irrigate without fertilizing.

Requisites of Good Pasture Species

A grass or legume intended for grazing should meet the following requirements. (1) It should give high yields of good quality forage. This implies high production during the growing season, the ability for rapid recovery from extremes, restricted flowering, a high leaf-to-stem ratio, and a high nutritive value. (2) The plant should have good persistence—that is, a high tolerance to grazing, slow maturity in order that quality will remain good, resistance to diseases and aphid attacks, and the ability to regenerate from seed. (3) It is important that the plant have a good capacity to associate with other species in order that the best balance of grasses or grass-legume mixes may be maintained. (4) It is desirable that the species be easily propagated and yield rapid returns.

Most tropical species have low seed set and readily shattering pods or inflorescences with nonuniformity in seed maturity. Warm, humid environments compound the problem of harvesting and storing high quality seed. The scarcity of seed of good germination, purity, and viability is a serious deterrent to improving tropical forage production. Fortunately, many of the species can be propagated vegetatively (cuttings, stolons or whole plant stems), but this expands the risks of spreading diseases and increases labor costs, particularly for renovating old stands.

In Puerto Rico, yields in green weight material 100 days after planting showed marked differences in development among four grasses—Congo, Star, Pangola, and Tanner. Three of the grasses were

propagated by cuttings alone, while Congo was established by both cuttings and seeding Star grass was the fastest grower, with 15,000 kg/ha. of fresh material, followed closely by Congo started from seed, with 13,500 kg, and Tanner, with 12,800 kg These were significantly above Congo started from cuttings, with 9400 kg, and Pangola, with 7000 kg Even the two low yielding stands were acceptable when one considers that it takes as long as 3 years for some grass stands in northern Australia to become ready for grazing

Improved Grasses

Productivity of grasslands in humid areas can be increased by the use of improved varieties of perennial grasses The following have given good results in various areas

Pennisetum purpureum (*Elephant Grass*)

It is native to Africa Varieties of this grass thrive from sea level to 2500 m This is probably the most extensively used grass for green chopping or soilage in the tropics Napier is the most common selection, but a large number of more productive types are available—e g , Merker, which gives outstanding performance, however, a selection (Number 536) has proven superior to the other varieties in Colombia Very high yields of forage can be obtained with nitrogen—up to 750 tons per hectare of green material per year These varieties are tall growing, vigorous clump grasses, hence, they are not used as extensively as some others for grazing, although in Puerto Rico, Napier has been equal to or superior to Pangola, Star, and Guinea for gains of growing animals and for lactating cows As a cut grass, palatability is only fair to good because of the heavy stem, which cattle and sheep do not relish Stands of Napier will be destroyed if they are repeatedly cut very young Height must be 1 meter or more to maintain a good stand, and by this time the stem leaf ratio is high All varieties of Elephant grass have given excellent response to nitrogen and irrigation

Panicum maximum (*Guinea Grass*)

Guinea grass, another clump grass, also is native to Africa and performs well over a wide range of altitudes Its forage production

varies considerably with soil fertility, rainfall, and intensity of grazing. Guinea responds well to nitrogen, giving dry forage yields of 70 tons or more per hectare per year. It seeds profusely but germination is low (2–20%). Because of this, it is frequently established vegetatively. In parts of Latin America and the Caribbean islands, it is regarded as among the best for grazing; and it is considered more drought resistant than several others. In Puerto Rico, Guinea has been superior in digestibility to Napier, Merker, Para, and Pangola. A chinchbug, *Blissus leucapterus*, which attacks all grasses, is especially harmful to Guinea on sandy soils during dry weather.

A large number of types occur, with a tremendous range in habit of growth, height of plant, size of stem, leaf length and width, and harshness of leaf. The medium to taller growing varieties are most frequently used for improved pastures.

Digitaria decumbens S. (*Pangola Grass*)

Pangola, an African grass, is well adapted from sea level up to 2000 meters but will grow up to 3000 meters. It is the most widely used grass in the warm climates of the Western hemisphere because it is good for grazing, is among the best for hay, can be used for soilage, tolerates periodic close grazing, and does not require mowing if undergrazed since the overly mature stems are easily trampled down, later sprouting at the nodes for regrowth. But it must have nitrogen otherwise it will not be very productive. Pangola is often severely attacked by the yellow aphid of sugarcane (*Sipha flava*). Although attacks occur most frequently during dry periods when forage is at a premium, aphids may also be a problem in wet weather. The infested grass almost stops growing, turns yellow to brown, and sometimes dies out. However, aphids can be controlled by pesticides. Pangola is sometimes attacked by scale insects and mealy bugs, principally on sandy soils, and it is subject to "stunt disease" in some areas.

Hyparrhenia rufa (*Jaragua Grass*)

Best adapted below 1500 meters, Jaragua will grow at over 2000 meters. It is used extensively in drier regions; it is highly productive until the stems elongate; it responds well to fertilization, irrigation, and intensive management; and it may yield up to 12 tons of high quality forage per hectare each 6–8 weeks under good management. However, it generally becomes quite stemmy and highly lignified

during the dry season, thus, burning is frequently practiced Currently, this grass is widely used in Peru and Brazil

Cynodon plectostachyum (*Giant Star Grass*)

It is endemic to East Africa So far it has not been widely used in established pastures This is because the native varieties are reported to have a cyanide content that sometimes makes it toxic for ruminants Nevertheless it is grazed in certain areas of middle Africa In Kenya it is grown some in leys for supplementary grazing and is used by small farmers in mixed farm rotations It is reported to develop prolific stands even on rather acid soils Through selection it should be possible to develop varieties with a low cyanide content (Davis and Skidmore, 1966) *Cynodon plectostachyum* should not be confused with "Star grass" reproted by Vicente Chandler et al (1964) as being an excellent grass for pastures in Puerto Rico This is a variety of *Cynodon dactylon* L commonly known as Star Bermuda grass

Cynodon dactylon L (*Bermuda Grass*)

There are many varieties of this grass The most widespread is Common Bermuda grass that grows in native pastures up to 2400 meters but it is low in productivity A number of selections as well as interspecific hybrids have been developed, the most common of which is Coastal Bermuda With nitrogen fertilizer, this variety has given excellent results for grazing and hay making, particularly in the subtropics of the U S Coastal is currently being replaced by a new hybrid, Coastcross 1 which has been selected for higher digestibility

Selections of a variety indigenous to parts of Central Africa—Star Bermuda—has become popular in both Australia and parts of Latin America It has given excellent results for grazing in Puerto Rico (over 900 kg TDN per hectare annually) In several respects it has proven superior to Pangola grass, namely yield, drought resistance and tolerance to heavy grazing It is also more resistant to aphids Its response to fertilizer is good and it seems to perform well under irrigation No doubt this grass will increase in popularity (In the discussion that follows Star grass refers to *Cynodon dactylon* L)

Panicum purpurascens R. (*Para Grass*)

Para grass, from Africa, is especially well adapted to wet soil conditions, withstands flooding and is good for low elevations but grows

in elevations up to 2000 meters. Since it is a low seed producer, it must be established mainly by stem pieces. It yields up to 12 tons of dry forage per hectare each 6–8 weeks with ample soil moisture and medium level of soil fertility. It responds well to fertilizer and may be heavily grazed during the wet season, although it will not withstand heavy grazing continuously. Para grass is seldom used for cutting because of difficulty in harvesting from the wet areas. There are two main varieties, one having a heavy, coarse stem and the other a finer stem; the latter is much preferred by animals. Para is not as palatable to cattle as Star, Pangola, and some varieties of Guinea. In well fertilized pastures of these species, the gains of cattle have been nearly twice that of Para in Puerto Rico.

Melinis minutiflora (Molasses Grass)

Molasses grass, another African species, occurs from 900 to 2500 meters and covers more extensive portions of hillsides between 900

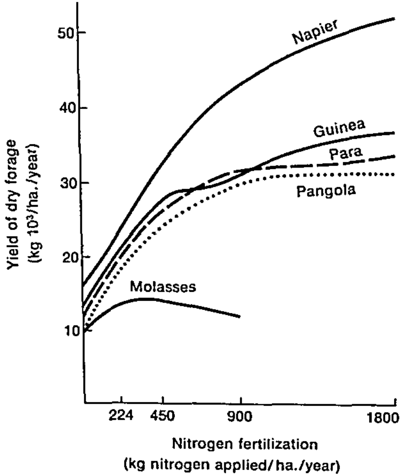

FIGURE 6.2
Effect of nitrogen fertilization on various grasses in Puerto Rico. (Adapted from Vicente-Chandler *et al.*, 1964).

and 2000 meters than any other grass It persists in acid soils (pH 4–5) and in soils low in phosphorus With favorable soil moisture and fertility it will yield 3 5–5 0 tons of dry forage in about 4 months when not overgrazed It does not respond well to applications of nitrogen fertilizer (Figure 6 2) nor does it withstand burning or heavy grazing, but it is a good seed producer Its seeds are very small, therefore, they should never be covered Best results are obtained when the seeds are mixed with ground limestone or other diluents to assure good distribution Since it is one of the best, if not the best, seed producer among tropical grasses and can be seeded without cover, the cost of establishing stands is less than that for many of the other grasses In addition, it has good compatability with tropical kudzu, a prevalent legume It is subject to ergot, caused by a species of *Claviceps*, but the infection is generally limited and of little importance, although it may occasionally reduce seed production Some claims have been made that cattle grazing molasses grass have fewer ticks than on other stands, but this has not yet been verified experimentally Probably the lower tick numbers are due to the sticky exudate from the grass, which inhibits movement of the ticks and clogs their respiratory passages

Pennisetum ciliare L (*Buffel Grass*)

Buffel grass is native to Africa, India, and Indonesia and is found widely in native pastures A selection called Blue Buffel has become popular in areas of western Queensland because of its drought resistant qualities Its usefulness will no doubt be relegated to semi arid areas since the quality is very poor when planted in humid climates It remains green in the dry season but mature stems become wiry

Pennisetum clandestinum HOCHST (*Kikuyu Grass*)

Kikuyu is one of the most extensively used grasses in the high elevations (>1200 meters) It is a very viable grass and often becomes a pest, particularly in areas where land is tilled for cropping It produces abundant seed and also propagates vegetatively In natural grasslands, Kikuyu production is very low, but with fertilizer and controlled grazing high yields can be obtained Whenever phosphate is added to the soil, white clover grows well among the stolons and contributes to grazing plus providing nitrogen for the grass

Tripsacum laxum (Guatemala Grass)

Guatemala grass is a tall growing, leafy perennial, which forms large clumps or stools but is easily uprooted by heavy grazing. It makes reasonably good silage or green chopping and has good drought resistance. But it is less productive, has a lower potential response to nitrogen, and is poorer in nutritive value than several varieties of Elephant grass.

This listing of grasses, although by no means complete, serves as an illustration of some of the grasses that have been utilized with

TABLE 6.6
Proximate dry matter (DM), total digestible nutrients (TDN), and crude fiber (CF) content (in percent) of some grasses used for grazing in tropical areas.

Name		Stage of growth	DM	Proximate composition of DM	
Scientific	Common			TDN	CF
Cynodon dactylon	Bermuda	Immature	19.1	56.9	33.3
		Mature	26.7	43.4	34.9
Cynodon plectostachyum	Star	23 days	20.1	63.8	22.6
		60 days	30.4	49.4	30.2
Digitarias decumbens	Pangola	23 days	20.5	62.4	27.4
		42 days	33.1	58.5	29.3
		84 days	30.7	46.6	30.0
Hyparrhenia rufa	Jaragua	Immature	29.7	54.7	28.9
		Mature	35.5	43.2	33.7
Melinis minutiflora	Molasses	Immature	25.6	52.1	39.5
		Mature	44.8	50.6	42.5
Panicum maximum	Guinea	Immature	25.1	52.3	36.4
		Mature	26.2	38.2	33.8
Panicum purpurascens	Para	Immature	25.4	49.7	34.8
		Mature	27.6	33.7	35.1
Pennisetum clandestinum	Kikuyu	Immature	25.0	69.0	20.9
		Mature	23.7	53.3	24.5
Pennisetum purpureum	Elephant	23 days	20.5	58.3	37.3
		60 days	21.0	48.8	36.4
Tripsacum laxum	Guatemala	Immature	25.3	62.2	35.6
		Mature	20.3	56.7	36.0

varying degrees of success in certain regions The research on grasses in warm climates is rapidly expanding One would be wise to consult technical journals, and in particular the recent Proceedings of the International Grasslands Congresses, before attempting to select the most suitable species for a given area

In Table 6 6 are given the proximate dry matter (DM), total digestible nutrients (TDN), and crude fiber (CF) content of most of the grasses described The TDN values, coupled with an estimate of maturity, can be employed as guidelines on the quality of forages available to the stock In the immature stages the nutritive value (TDN) of nearly all the grasses will exceed the 55% level recommended by NRC, but one ought to be equally aware that by the time growth reaches 60 days or beyond, either expanded area per animal is needed to permit selectivity or supplements in the form of concentrates are necessary for good performance

Choosing the Forage

From time to time the livestock producer may hear of fabulous returns someone has obtained with a forage But he should carefully weigh the information against his own requirements, considering particularly (1) intended use, (2) likeliness of adaptation to local soil and moisture conditions, (3) minimum water needs, (4) tolerances of the forage to shade or open sunlight, poor drainage, and minor element deficiencies, (5) extent the forage will provide ground cover to restrict erosion, (6) ability to withstand heavy grazing, cutting, and burning, (7) maintenance requirements, particularly with respect to competition with undesirable species, and the frequency of cutting or clipping required to maintain quality, (8) the time after establishment before the stand can be used, and (9) the value of the land for alternative uses

The topography of the land also affects the selection For instance, on level or gently sloping land grasses that respond to heavy fertilization and are adapted to cutting or to intensive grazing should be used On steep slopes, mixtures (e g , kudzu-molasses grass stands), which produce reasonably well with little fertilization, are preferred

Intended use is probably the most important consideration in choosing forages Inherent weaknesses of the forages can often be counteracted by managerial skills and certain adjustments in the environment

Since the utility of forages varies widely, the producer must ask himself a number of questions (1) Is the forage to be used as a sup-

plementary item in more permanent grazing stands? (2) Will it be subject to continuous grazing or needed to fit in with rotational grazing of other stands? (3) What species of livestock will be used or what age animals? (4) What is the expected carrying capacity (the number of animals that can adequately be carried per unit of land)? (5) Will the forage be used primarily as a source for green chopping, hay, or silage? From the brief description of tropical grasses, it is evident that the different types have different uses. Napier grass ranks medium to good for grazing and excellent in yields for green chopping, but would provide medium to low quality silage due to the high moisture content and be almost worthless for hay. Pangola grass, on the other hand, is good to excellent for grazing or hay, but only fair to medium for green chopping or silage, mainly because of its vegetative characteristics, and by the time Pangola reaches a height for good yields by cutting, the quality is fair to poor.

Seeding of Grasses

Planting should be timed with moisture to insure that the stand will have ample opportunity to become established before being subjected to dry weather. Sufficient seed should be used to produce 100,000–200,000 seedlings per hectare in order to obtain a thick stand rapidly. The quantity of seed required depends largely on germination percentage. For instance, 30 kg seed per hectare are recommended for Guinea grass since its viable germination is usually 3–5%, in contrast to 12–15 kg for Molasses grass, with a germination of 80%.

For good stands of Napier, it is best to use 3.5–4.0 tons of mature stems-cuttings per hectare; for Pangola, Star, Tanner, and Congo, 1.8–2.0 tons; and for Para, about 2.5 tons. If Guinea is to be established rapidly by sprigging (stems with roots), the plantings need to be at 1 meter intervals. Stands can be developed by wider spacing but the time required to get a thick stand is correspondingly longer.

In Puerto Rico, Pangola grass has been established successfully by plowing cleared land only once, dropping 4 to 6 stems continuously in every other furrow, and relying on the next furrow slice to partly cover them. For other plantings, particularly involving the change from a grass stand like Para to those like Pangola, Congo, or Star, several plowings and even spraying with herbicides may be required. It may take 6 months to get a stand of one of these grasses established in an old Para grass stand, whereas the time may be one-half that when the land is converted from cropping to grass. Due to so many intangibles, it is virtually impossible to provide guidelines on

cost of establishing stands If the material for cuttings is on an adjacent field and the land is relatively clear, the cost per hectare, including fertilizer and herbicides, may be as low as one hundred U S dollars per hectare, but if the land must be cleared of trees and brush and drainage installed, the cost may reach several thousand dollars per hectare

Use of Fertilizer

Improved grass varieties with high genetic potential demand greater sophistication in production Much of the value of improved grasses can be lost through poor stands, low soil fertility, and wasteful management.

Varieties with high yield potential are characterized by their ability to utilize the elements of the environment most efficiently to produce abundant growth Fertilizer, particularly nitrogen, is one of the most potent means of improving productivity of grasslands Most grasses respond dramatically to nitrogen fertilization in the presence of adequate levels of phosphorus and potash When legumes are present in the stand, nitrogen requirements decrease, but higher levels of phosphorus and potash are required and must be applied if the soils do not possess adequate amounts A large number of experiments have clearly shown increases in the yields of forage dry matter and animal products resulting from application of nitrogen fertilizers Higher protein content of the forages also usually accompanies increased yields In spite of these excellent results, probably no more than 1–2% of the forage acreage in the warm climates is fertilized and a much smaller fraction of that is fertilized adequately A decision by the operator to use fertilizer is based largely on economic factors, including availability of capital and demands of competing crops

Few of the soils of Puerto Rico have been found capable of much forage production without fertilization Unfertilized, volunteer forage yields only 5000 kg/ha and unfertilized Napier, 8000 kg/ha, but well fertilized Napier gives yields up to 31,000 kg/ha These findings have led to experiments with different applications of nitrogen The results of trials with various grasses are shown in Figure 6 2 The yields of Guinea, Pangola, and Para grasses increased sharply with nitrogen levels up to 450 kg, rising at a slower rate up to 900 kg, while those of higher yielding Napier grass increased rapidly with nitrogen levels up to 900 kg per hectare annually Molasses grass did not respond to nitrogen applications above 224 kg In fact, dry forage produced per kg of nitrogen for this grass decreased sharply with increasing nitrogen

rates. It was found that about 50% of the nitrogen applied at rates of 450–900 kg/ha was removed by the four highest yielding grasses. The grasses responded much more rapidly to nitrogen application during the season of fast growth than during the drier, cooler season of slow growth. The protein content of the forages, on the other hand, was considerably higher during the seasons of slow growth.

In the Puerto Rico experiments, less nitrogen was required to produce a given yield if the harvest interval was increased, but more nitrogen was required to maintain the desirable protein content in the forage when a longer harvest interval was used (60–90 days). It took 900 kg of nitrogen to produce 28,000 kg of dry forage using a 40–day harvest interval, compared to only 336 kg with a 60-day interval, and 112 kg with a 90-day interval. With a 40-day harvest interval, 450 kg of nitrogen was required to produce forage with 10% crude protein content; whereas, 900 kg was required if the grass was cut every 60 days and more than 1800 kg if the grass was cut every 90 days. Figure 6.3 shows that both the proportion of leaf, and the protein content decreased with length of harvest interval. In contrast, the dry matter and lignin percentages increased. This further illustrates the desirability of harvesting grasses at short intervals to obtain maximum quality forage, particularly if heavy applications of fertilizer are used.

Numerous other experiences with applications of nitrogen are reported in many technical journals from countries in Latin America, Australia, and Africa. They all show the importance of classifying and choosing tropical grasses on the basis of their response to nitrogen. At low levels of nitrogen, such as in grass-legume mixes, the yields of most grasses are about the same; however, at higher nitrogen levels grasses demonstrate marked differences in yield.

In areas of Latin America where applications of phosphorus have been tested, there has not been much response, as measured by increased phosphorus content in the grasses. Applications to the land apparently do not become readily available to the grazing animals through the forage. In Colombia, for example, it was found that supplements of phosphorus given directly to the animals doubled the gains on grasses as compared to applications to the land.

Usually in humid areas there are small reserves of calcium in the soils. But under intensive crop production these reserves are rapidly depleted and acidity increases. Thus, with the application of nitrogen, liming must be considered in the overall fertilizer program.

The optimum quantity of fertilizer to apply to forages depends on many factors. More fertilizer can be used profitably as land values increase. But when land is cheap and not too poor in fertility, it is frequently economically feasible to utilize more land, with managed

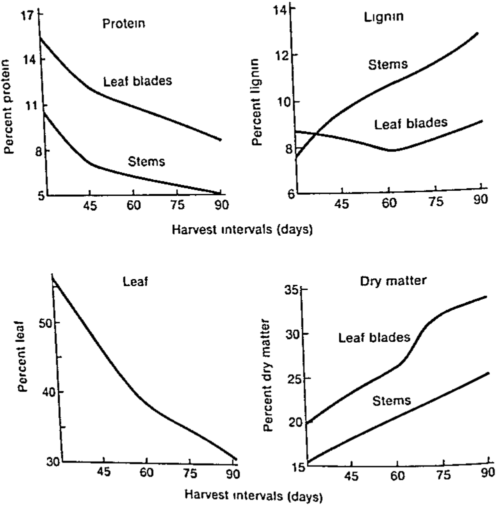

FIGURE 6.3
Effect of harvest interval on composition of Pangola, Guinea, and Napier grasses in Puerto Rico (Adapted from Vincente-Chandler *et al*, 1964)

stocking rates and no fertilizer It may sometimes be wise to fertilize only a portion of land for growing forages to be harvested or grazed intensively, rather than to attempt to fertilize large areas However, heavy nitrogen fertilization may be warranted when protein concentrates are expensive and it is necessary to rely on forages as the main source of protein When heavy fertilization is employed, samples of soil should be tested periodically as an increase in nitrogen or potassium will raise the requirements for the other nutrients about threefold

Where there is no distinct dry season, equal applications of amounts of fertilizer two to four times a year have proven most successful—the higher the level of nitrogen, the more several applications give most effective use. Where there is a distinct dry season and

no irrigation, one application of fertilizer (500–700 kg/ha) near the end of the rainy season is best. This will stimulate plant growth and thereby provide more grazing during the dry season. It has proven more satisfactory than a single application early in the dry season or split applications in early and late wet season. Of course, the most satisfactory amount and frequency of application of fertilizer depends upon the intended use of the forage, the seasonal changes, and the natural soil fertility.

From the experimental evidence to date, it seems wise to invest inputs to intensify forage production in the humid tropics. However, because of other physical factors involved, arguments could be developed both pro and con. Perhaps an intermediate attitude is most logical, meaning in some instances heavy fertilization will be feasible and others not, at least for the foreseeable future.

An illustration of how inputs of fertilizer and other systems of management influence performance of cattle can be drawn from the more than 12 years of experiments with dairy and beef herds in a subtropical area, Iberia Livestock Experiment Station in Louisiana. The initial feeding program for the dairy herd consisted of permanent pastures, mainly of grasses, except for early spring when there was some clover for grazing. Young stock and dry cows received grazing alone, while the lactating cows were fed some silage and locally produced hay plus concentrates according to milk yield. The pastures were fertilized with 200 kg of balanced fertilizer and top dressed with 50 kg of nitrogen once per year, with renovation at approximately 4 year intervals. Under this regime the growth rate of heifers for herd replacements was substandard and the milk yield per lactation low for Holsteins (Table 6.7). With improvement in quality and quantity of roughages, average milk yield per cow increased over 100%. Although the dry-lot regime required a high level of inputs, including about 3 times more fertilizer, this proved least expensive in terms of Mcal energy per kg of milk produced and gave the highest dollar return over feed costs.

The initial program for beef production at the Louisiana station was to utilize native grass pastures throughout the year for cows and calves. The pastures received a single application of fertilizer annually, similar to the program for the daily herd. Cows were bred to calve January–March, when native grass pastures were generally poor. Under this regime annual calf crops ranged from 60–67%. The first improvement was to remove surplus pasture of early summer as hay or silage which was utilized for supplementary winter feeding. After removal of the cut grass 50 kg of nitrogen was applied per hectare. The use of silage to supplement the pastures increased calf

TABLE 6.7
Annual average milk yields for Holstein Cows in the Gulf Coast area of Louisiana under various feeding regimes (65–104 cows/feeding regime)

	kg/lactation
Pasture[a] and concentrates[b]	3465
Pasture + supplemental grazing[c] (summer) and concentrates	4193
Pasture + supplemental grazing[c] (summer and winter) and concentrates	4845
Pasture + supplemental grazing, silage and concentrates	5148
Supplemental grazing, silage and concentrates	6038
Dry lot with stored feeding of silage ad lib + 2.2 kg hay/day and concentrates	7119

[a]Pasture refers to grass stands used 4 or more years before renovation
[b]Concentrates fed at rate of 1 kg/3 kg of milk throughout.
[c]Supplemental grazing refers to seasonal crops planted for grazing or silage production

crops to about 72%, with lower calf losses. The next stage provided for part of the land being planted to corn or sorghum for silage, which was used for supplementary feeding in the late stages of pregnancy and the early part of lactation. The nutritive value of the corn and sorghum silages were higher than for the grass silage, thus a further increase in the annual calf crop as well as an increase in both the proportion of calves weaned and the weaning weights. The latter regime gave the highest economic returns.

These experiments, as well as numerous others, indicate that improved pastures produced with fertilizer plus management, are needed for satisfactory reproductive performance and for growing stock supplementation. It is also evident that dairy production should only be attempted on improved pastures in the humid subtropics.

Legumes for Pastures

Some legumes are found in the natural grasslands but where heavy grazing has been practiced for a long while, the proportion of legumes is generally low. Legumes have great potential for enhancing grazing resources, largely because of their ability to provide a source of nitro-

TABLE 6.8
Animal performance on Townsville lucerne-grass pastures in Australia

	Live weight gains (kg/ha)	
Type pasture	1962-63	1963-64
Native grasses	33	21
Native + Townsville lucerne	118	64
Native + superphosphate	87	55
Native + super + T.L.	[illegible]	103

Source: Shaw 1964.

among grazing ruminants. Also, most legumes in their indigenous form do not possess the characters required to make them successful pasture plants. Some, like subterranean clover, are insignificant in their country of origin but are quite useful in other areas. Research on legumes is at present inadequate to resolve the question of their value in the warm climates. However, several legumes have already been utilized with varying degrees of success. Both subterranean clover and Townsville lucerne have performed well in Australia. They grow satisfactorily on poor, acid soils, show a tolerance for aluminum excess, and respond to superphosphate applications in the presence of molybdenum. Unlike subterranean clover, Townsville lucerne grows well on soils low in phosphorus due to the unique ability of its roots to extract this element from sources deficient in it. These two legumes have high seed yields, are easy to establish, show good tolerance to grazing, and have moderate to good palatability. In northern Australia cattle lick up Townsville lucerne seed from the ground in the dry season. When Townsville lucerne was sown into Spear grass (*Heteropogon contortus*), two phase pasture was provided—Spear grass for summer grazing and Townsville lucerne for autumn and early winter.

Incorporation of Townsville lucerne into native pasture, along with annual applications of 100 kg/ha of molybdenized superphosphate, increased carrying capacity from one animal per hectare to two, gave greater live weight gain per head (up fivefold), and quicker turnover of stock (marketing 1 to 2 years earlier than on pure native grass pasture, Table 6.8). The increase in animal performance, particularly with the mixture plus superphosphate, was attributed to the increased length of feeding period and the palatability of the lucerne through the dry season as well as a high crude protein content of 8–9% (50–55% digestible).

Dolichos uniflorus

When mixed with native grasses, *Dolichos uniflorus* also shows promise. It is a vigorous, twinning, herbaceous annual, which sets a heavy crop of medium sized seed of good quality and maintains a high feeding value through the dry season. In a trial in northern Australia, during 13 weeks of the dry season, steers gained 60 kg per head, while cattle on native pasture at this time were losing weight rapidly. The major drawback of this species, as a component of permanent pasture, is lack of seededness; but plant breeders should be able to over come this fault.

Trifolium alexandrium (Berseem Clover)

Berseem clover is the most widely used legume in northern Africa and southeast Asia. An annual, it nevertheless produces well and has a high crude protein content (12–20%) and good digestibility (up to 68%). There are many published reports from Egypt and India on the value of this crop for feed of buffaloes, cattle, sheep and goats. Its chief disadvantages are the need for reseeding annually, high water requirements, and cessation of growth with the onset of hot weather. These characteristics restrict it to a forage resource in a limited season (December–May), nevertheless it can provide an excellent supply of feed when little else is available in many areas.

Trifolium incarnatum (Crimson Clover) and Trifolium repens (Louisiana White Dutch Clover)

Crimson clover and Louisiana White Dutch both thrive well in the subtropics. Their germination is fair to good. But they require cool weather and high moisture, and consequently they are at their best when grasses are also likely to be reasonably good. Hence, they do not help in the dry season when the needs of grazing animals are most critical.

Dolichos axcillaris

A perennial species, *Dolichos axcillaris* has distinct promise for areas of the wet-dry tropics. It has excellent drought resistance

and will persist under grazing in 76 cm rainfall areas It yields over 3000 kg of dry matter per hectare, with 12% protein content and excellent digestibility (50–60%)

Medicago sativa (Alfalfa)

Alfalfa has been tried in numerous areas of the tropics At higher elevations (>1500 meters) it has done reasonably well as a hay crop, but stands are short lived due to leaf and crown diseases and competition from grasses There are some varieties indigenous to tropical areas, but research on potential development of these has been very limited Recently there has been a strain developed in Peru that is performing much better than other varieties in both lowlands (<1000 m) and highlands (up to 4000 m)

Leucaena leucocephala

The leguminous tree *Leucaena leucocephala*, is indigenous to Central America but it has become widely grown in Australia, Hawaii, Philippines, Jamaica, New Guinea, and other humid tropical areas Because of its small leaves, which restrict air movement very little, it makes almost the ideal shade for animals It has been used quite successfully in Jamaica by planting at 20 m intervals in Pangola pastures to serve as a means of protecting the animals from solar heat during the day and to provide a source of nitrogen However, it develops beyond the reach of animals, which limits its use for grazing

Kapok Bush and Karoo Shrubs

The use of *kapok* bush in Western Australia and Hawaii and *karoo* shrubs in South Africa suggests that more attention might well be given to plants other than grasses and legumes—especially shrubs and browse plants, as opposed to softer, less stemmy types such as *Desmodium* spp

Pueraria phaseoloides (Tropical Kudzu)

Tropical Kudzu is the legume most widely tested at low elevations (<3,000 m) in the Americas, but its use has been limited It

does best as a forage when grown in association with an adapted grass, such as Molasses, Para, Guinea, or Napier; but it does not do well with Bermuda, Pangola, or Star grasses. Tropical Kudzu has much higher protein, calcium, and phosphorus contents than the grasses. Although it may grow profusely and provide excellent quality feed, it does not withstand heavy grazing, does not do well in areas with extended dry periods, and creates serious handling difficulties when attempts are made to cut it for hay. However, it is easy to establish from seed, has no major pests, and is very aggressive in choking out most weeds. The seed should be soaked in water for 24 hours before planting to accelerate germination. The seeds do not need covering, but inoculation before planting is recommended. About 6 kg of 80% viable seed are recommended per hectare. Some nitrogen and phosphate should be applied at time of seeding.

Centrosema pubescens (*Centrosema*)

Centrosema is a low growing, trailing, leafy perennial that is easily established from seed, regenerates freely, and smothers weeds. It has a crude protein content of 16–19% of dry matter and grows very well in association with a number of grasses—e.g., Molasses, Guinea, Napier, Star, and Para. When planted with grasses, 2–3 kg of seed are needed per hectare. Because of its tendency to trail along the ground in a pure stand, it gives better results for grazing in a mixed stand. In Nigeria, pastures of Centrosema plus Star grass raised live weight gains of cattle 21% during the wet season and 50% during the dry season, over gains from grass alone. Similar experiences have been reported in the Philippines with pastures of Centrosema and Para grass.

Stylosanthes gracilis

If consumed by livestock before flowering, *Stylosanthes* has a nutritive value comparable to alfalfa. A persistent, highly drought-resistant perennial, it grows in association with Molasses, Guinea, and Para grasses, and will grow where lucerne will not grow. However, it is inclined to be woody and does not withstand trampling. It is a popular pasture legume in Hawaii, Kenya, and Uganda. But because it does not graze as well as desired in most areas, it might serve better as a protein supplement in a dehydrated form.

Potential for Legumes

There are a large number of legume species indigenous to South America, but these appear in the pastures quite erratically. And native legumes do not necessarily provide the required bacteria for nitrogen fixation, as generally thought. The findings in Australia suggest that most could be improved through the use of better inoculants. Thus the culturing of tropical legumes should be reevaluated in various micro-environments. It may be that bacteriology holds the key to success of tropical legumes. The supply of calcium influences the formation and functioning of nodules, but research in Australia shows that bacteria are not calcium sensitive. They require calcium in trace amounts only, although the host legume plants require quantities of this element. Tropical legumes seem capable of obtaining calcium from acid soils, in contrast to temperate zone legumes. They are also more tolerant of soluble aluminum and manganese in acid soils than temperate legumes. Investigations in Australia showed that other elements, such as sulphur and cobalt, may be influencing factors, but such information is not available for most other tropical areas.

The specificity of bacteria host legume relationship appears important. In both Colombia and Australia, the legume *Lotononis bainesii* grew only to about 15 cm without flourishing until a strain of *Rhizobium* found among introductions from Africa proved to be specific and efficient in symbiotic nitrogen fixation. With a satisfactory inoculant, this legume is becoming of commercial significance in Australia.

To establish a grass-legume pasture, preparation of a clean seedbed is recommended. The degree of preparation will depend upon the nature of the stand being replaced, but at least 80% of the competition should be removed. This means that in vigorous grass stands, ploughing is required. Lighter seedbed preparation will suffice in weaker grass stands. Occasionally, herbicides may be used to suppress competition from the existing stand to get the legume started. This procedure has the advantage of reducing the risks of erosion, conserving moisture, and costing less than ploughing. When Molasses grass is seeded together with a legume, such as Kudzu, it is best to alternate the rows or holes so that the faster growing grass does not compete with the slower growing legume. With Napier and Para, the grass stems should be laid in furrows and completely covered with 2–4 cm of dirt. In these plantings, Kudzu may be broadcast or seeded in alternate rows.

The best time for planting is after the rainy season has begun. Drill sowing of lime pelleted, inoculated seed in contact with ferti-

lizer has given best results in Australia. Broadcast sowing on rough lands has also been successful. At the time of sowing an application of phosphorus is recommended.

There is no cure-all for the problems of forage production in the warm climates. In the humid, subhumid, and semi-arid areas of the tropics and subtropics, where native grasses usually provide submarginal feed supplies, the incorporation of legumes—together with better management—can produce significant improvements. In other areas, particularly the humid regions, replacement of the native grass by an improved variety is most successful. With respect to total yield and carrying capacity, highly fertilized grasses give best yields, but this approach is limited by economics. Thus, there is no panacea for forage production in the tropics. There are tremendous potentials but the best solution rests with many factors. It should be kept in mind that most livestock have the capability of storing body reserves of fat, which may be used in times of low energy intake but their capacity for building reserves of protein is very restricted. To obtain satisfactory performance a constant source of protein is required from young grasses, legume-grass combinations or direct supplementation from other sources, such as concentrates made from oil seeds. The most feasible source will depend largely upon the individual farm situation. It should also be borne in mind that the methods of establishing pastures must be varied to suit particular conditions on the farms. This may or may not mean that incorporation of legumes is warranted.

IMPROVING OF SEMI-ARID GRASSLANDS

The principal semi-arid grasslands of the warm climates lie in two regions of Africa (0–15°N latitude and 10–30°S latitude), some in the Saudi Arabian peninsula, in the Indian subcontinent between 10–20°N, in the eastern and northern portions of Australia from 18–30°S, and in relatively small areas in Mexico, Colombia and Brazil. For the most part these areas are distant from the major centers of population, hence their use has largely been for grazing of sheep or cattle. Research on methodology of the best means of utilization of these grasslands is very limited. Present recommendations are based principally on studies in the western U.S. and northern Australia.

Currently, the consensus is that improving the productivity of the semi-arid grasslands involves arresting deterioration, as illustrated in Figure 6.4, and reversing some of the traditional views on management. The restoration process is often painfully slow unless certain

FIGURE 6 4
Semi arid area in the northern portion of South Africa. Grass has almost completely disappeared leaving only thorny brush (Courtesy J C Bonsma University of Pretoria)

treatments are applied—e g , control of brush, seeding of depleted areas, and deferred grazing Because of the relatively low potential for forage production in most rangelands of the semi arid zones, economic inputs directed toward improvement must also be rather low except where multiple use considerations justify additional inputs

Seeding probably offers the greatest opportunity for improving productivity in semi arid areas This practice has been utilized to a considerable extent, especially in more favorable environments Most seeding has been accomplished with introduced species or native ecto types, as yet few improved varieties have been developed Usually seeding must be preceded by a treatment to remove the existing vegetation This may involve tilling or removal by hand If the cover is largely bush, it can be removed by dragging a heavy chain suspended between two tractors over it Herbicides or fire may also be employed to reduce competition The most successful seeding method has been drilling at the time of most advantageous soil moisture and temperature

Areas unsuited to seeding necessitate different approaches, such as brush control carried out by spraying or various types of grazing, followed by slow natural restoration of more productive stands But deferred and rotational grazing have proven successful in many areas

and may be especially effective if deferment coincides with certain critical periods in the growth cycles of the more desirable plants. Placement of water and salt for livestock, by assuring better distribution of grazing animals, can often relieve severe grazing pressures. Grazing practices such as these should follow reseeding.

Fertilizers have been utilized on a few of the better range sites in the U.S., Mexico, Brazil and Kenya, but soil moisture usually limits the rates that are economically feasible to rather moderate levels. Australian researchers oppose the use of fertilizer. They recommend the legume, Townsville lucerne, be planted on at least portions of each farm. This procedure has the advantage of improving the grass by making more nitrogen available and extending the grazing season. After the grass is dry and low in palatability, the cattle and sheep feed on the lucerne plant and consume the seeds.

Bonsma and Joubert (1957) identified the semi-arid lands of South Africa and made recommendations on size of farm, best species for various areas and management practices for these lands. The Bonsma-Joubert proposal has become the basis of governmental programs on livestock production, rules for stocking rates and producer incentive programs.

Because of the low economic value of the semi-arid lands, the amount of attention directed to methods of improving productivity from these lands will continue on a very modest base. Nevertheless, the few experiences of attempts to increase the productivity of these lands are encouraging and indicate worthiness of further investigation, especially in central Africa.

PROSPECTS FOR LIVESTOCK FEEDING IN THE WET-DRY CLIMATES

The wet-dry areas have alternating wet and dry seasons. They are transitional between the rainy and monsoon tropics on the one hand and the semi-arid climates on the other. In these areas, there is a distinct dry period of 5 or more months. The principal areas having this kind of rainfall distribution are in western Central America, northwestern South America, the interior uplands of Brazil and adjacent countries (0–21°S latitude), south-central and eastern Africa ranging from 12°N to 21°S latitudes, western Madagascar, most all of India and southeast Asia, and the northernmost portion of Australia.

According to Whyte (1968) and others, the prospects of livestock production in the wet-dry areas from grazing are poorer than for the semi-arid grasslands. In Australia, Africa and the western hemisphere,

the major vegetation consists of what Whyte classes as tall growing grasses They grow rapidly and produce rather high yields following the onset of the rainy season At the best stage their nutritive value is medium to low but when they become mature the nutritive value is very low Cattle or sheep on this kind of grazing will make modest gains for 4-6 months of the year as illustrated in Figure 1 4 but will have high losses in weight for 3-5 months Thus annual net gains per head for adult cattle range from 25-50 kg Usually it is not economically feasible to apply fertilizers and the cost of replacing the tall growing grasses is high, hence there is a dilemma on means for improving animal output Another deterrent contributing to the dilemma is that the grass stands are generally in areas of high tick infestation that transmit numerous diseases

Preliminary results from tests in Colombia indicate that some of the natural grasslands can be partially or even wholly replaced by Molasses grass The Molasses grass seeds are broadcast at the end of the dry season when the grasses are dead Apparently there is enough dew formed under the dead grass to help get the Molasses grass started so it can compete with the native grasses Molasses grass is not deemed satisfactory where fertilizer is applied but its tolerance to acid soils and low fertility and its reasonably good nutritive value constitute an improvement in Colombia

For the wet dry region of Australia, it is recommended that a portion of the native grass stands on each farm be replaced with some improved species of grass or a grass-legume mixture Generally it is too costly to replace the native grasslands on the entire farm But it is felt that some improved pasture is worth the investment as it has been shown that both calf crop and breeding efficiency of cow herds can be increased by using limited areas of improved pastures as a supplement for the natural grazing (Norman and Stewart, 1964)

In the Congo, it has been found profitable to plow up the stands of native grasses and replace them with Guinea grass, *Brachiaria ruziziensis*, or one of the improved varieties of Congo grass (Jurion and Henry, 1969) Similar procedures are being tested in Kenya, especially around Lake Victoria

Although results from test areas appear encouraging for obtaining better yields of forage and forage of higher quality, some writers, including Bisschop and Groenewald (1963), contend that man's actions are the major reason for poor forage yields in Africa, south of the Sahara They hold that livestock keeping in a large portion of Africa has gone through one or more three phase cycles over the past 100 years Bisschop and Groenewald start their cycle following a serious disease outbreak In the first phase the impact of the endemic or epi-

demic disease causing the high losses of stock has run its course or the disease has been brought under control by vaccination or other measures. While the livestock numbers are lower following the disease outbreak, the grasslands have an opportunity to recover. In the second phase, the animal population flourishes from the better feed supplies and because the threat of disease remains low as a result of acquired immunity or the use of control measures. Gradually animal numbers increase beyond the satisfactory capacity of the grasslands. In the third phase, the consequences of overstocking are experienced: soil fertility and productivity decline and problems of animal health increase. These conditions lead to termination of a cycle. Obviously the cycles will repeat unless broken through introduction of balanced farming. This constitutes livestock farmers adopting practices of pasture management and renovation of grazing by such means as discussed above. Bonsma and Joubert (1957) hold much the same views about the needs for balanced farming to enhance livestock development in South Africa.

The report by Rattray (1960) and the accompanying map are excellent references on the grasslands of Africa. Jurion and Henry (1969) have compiled data from many experimental trials conducted in Africa dealing with tests on the productivity of various grasses and methods for establishing stands of grasses. These two references can be used as guides not only in the field of grassland management but also in the wider realms of land use generally, especially for central Africa.

Much of India falls into the wet-dry tropical classification but the problems of bringing about change are quite different from those in the other regions where there is land available that can be used for forage production. In India the pressures on land for the production of food for humans and for maintaining cattle and buffaloes for agricultural power take priority over production of forages for milk or wool. Ray (1963) describes the present situation on feed problems by dividing India into three broad zones. These are depicted in Figure 6.5. Rainfall distribution and soil characteristics are the main governing factors for the major crop of each region. The paddy regions have rainfall of about 127 cm, but the soil is deficient in nitrogen, organic matter, and phosphorus. The millet region is intermediate in rainfall (75–125 cm) and has better soil than the paddy region. The wheat region is lowest in rainfall. The soil is low in nitrogen and organic matter but generally adequate in calcium and phosphorus.

In the paddy region, practically all the usable land is devoted to the production of food for human and cash crops; thus cattle and buffaloes exist primarily on plant by-products such as straws, brans, husks

FIGURE 6.5
Some factors limiting feed supplies for livestock in India according to the major agriculture crop of the regions. The Paddy region has 127 cm rain with the soil deficient in nitrogen and phosphorus and low in organic matter. The average milk yield is 0.8 kg/day/cow and 1.5 kg/day for buffaloes. The Millet region has 75–125 cm rain with soils better than in the Paddy region. Milk yield is higher too: 1.8 kg/day for cows and 2.8 kg/day for buffaloes. The Wheat region has <75 cm rain, with soil low in nitrogen and organic matter but generally adequate in calcium and phosphorus. The average daily milk yield is 2.3 kg for cows and 4.1 kg for buffaloes. (Adapted from Ray, 1963)

and oil cakes. The main source of green fodder, very little of which is cultivated, is grazing and weeds or grasses cut from the fields in the wet season. In the millet region, straws are the principal roughage. Since there is less pressure on the land, the cattle and buffaloes get some supplementary feeding. Wheat straw is the main source of feed in the wheat region but with more irrigation facilities a sizeable segment of the land in this region is used for fodder crops.

Though underfed, by and large cattle and buffaloes get greater quantities of nutrients in the wheat zone than in the other two zones. The underfeeding of protein is the most serious problem. The crude

protein content of India's natural grasses is about 11% in August (end or near end of the monsoon season), but falls to 5% in October (dry season). The nutritive value further diminishes through the winter until the rain begins in May or June.

Ray estimates that the number of adult bovines per hectare of cultivated fodder crops in the three zones are 125, 50 and 7, respectively. These high animal densities, coupled with high human numbers, means India will be unable to develop grazing lands to alleviate the fodder shortage. But with the expanded use of new varieties of cereal grains, the prospects of incorporating more forage production into crop rotations seem good. Research along these lines is under way.

MIXED GRAZING AND CROPPING

The integration of grazing with nut, oil, or fruit crops is being advocated as a profitable system of grazing management. This has been practiced for a long time in the coastal regions of many tropical areas, where cattle grazing has been combined with coconut production. The purpose is twofold: control of weeds and higher total return per unit of land. A number of successful enterprises are underway. In the Philippines, and elsewhere, coconut stands are being seeded with improved grasses to increase yields. Stands seeded with Para grass and fertilized will easily carry one animal per hectare. New stands of coconut trees are being planted at 10 m^2 intervals to allow sufficient light for grass. Coconut trees provide an almost ideal environment for cattle production in coastal areas because the trees always move with the air currents to reduce animal heat load. To make the coconut-grass program feasible, however, there must be adequate rainfall—at least 180 cm per year—and addition of fertilizer. The use of grazing in conjunction with coconuts reduces yields about 50% from those obtained from full grass stands.

Grazing is also combined with pineapple plantings; the rougher land adjacent to the pineapple fields can be used for grazing, as can the refuse from the pineapple plants after fruit harvest. In conjunction with the sisal crops, guinea grass may be interplanted and the sisal plant residue used as supplementary feed. Oil palm plantings have not produced as good results as coconut stands in mixed grazing and cropping programs because the palms seem to permit insufficient light to pass to the grass for good growth.

PROBLEMS OF MINERALS AND VITAMINS

Mineral deficiencies appear widespread throughout the N-S 30° latitudes, particularly in livestock whose major source of feed is grass The same livestock show little evidence of serious vitamin deficiencies Problems of vitamins may, however, be a yet unrecognized problem with high rates of fertilizer application There have, for example, been several reports of vitamin A deficiencies in dairy herds fed high levels of corn silage made from corn that had received large applications of nitrogen

Some areas of Latin America have reported calcium deficiencies in cattle, as evidenced by weakened bones, slow growth, low milk yields, and occasionally tetany Lactating females are the most susceptible to shortages of calcium when on grazing alone This may be more of an imbalance with phosphorus than a deficiency since calcium deficiency is unlikely to occur in ruminants except when they are lactating heavily without adequate supplement.

Shortages of phosphorus in the soil and forages have been reported all over the tropics and subtropics It has been found that the high rainfall, open grassland pastures of South Africa are deficient in phosphorus for cattle throughout the year The mixed grassland and shrub pastures are deficient 11 months, the subtropical thorntree and grassland pastures deficient 7 months, and desert grassland pastures deficient 10 months of the year (Table 6 5) Even the highland pastures around Lake Victoria in Uganda are deficient in phosphorus throughout the year for lactating cows The natural grassland pastures of northern Australia appear deficient in phosphorus practically all year In the Llanos region of Colombia, grazing heifers gained 50 kg more per head on native grassland pastures in a 9 month period when given supplements of phosphorus plus salt than when given salt alone

Severe deficiencies of phosphorus in animals cause general weakness and loss of weight. Cattle on deficient grazing or stall feeding will continually lick each other and, while standing, will lash the tongue out to the side of the mouth Lack of phosphorus also seems to reduce feed intake of cattle Some researchers have associated low dietary intakes of phosphorus with low breeding efficiency in cattle but this has not been proven experimentally

Since calcium and phosphorus are closely interrelated in metabolism, it is difficult to evaluate requirements and functions of one without the other Although a Ca P ratio of 2 1 is recommended for ruminants, they seem able to tolerate wider Ca P rations than nonruminants A ratio of 4 1 has proven suitable for cattle in drylot on

full feed provided the phosphorus intake meets minimum requirements. There is some evidence that grazing cattle can tolerate Ca:P rations up to 12:1, but ratios below 1:1 retard growth. This implies that in areas where calcium or phosphorus deficiencies have been reported, the major problem may be to an imbalance of these two minerals.

Poor reproductive performance has been frequently reported in copper deficient cattle. Copper therapy seemed to increase the conception rate of heifers on open range grazing but did not improve the conception rate of cows. Reduced milk yields may be associated with a suboptimal supply of copper in the diet. When their mothers are on rations deficient in copper, suckling calves also may show signs of copper deficiency 2 or 3 months after birth.

Hemoglobin, an iron containing protein in the blood, is decreased by deficiencies of copper or cobalt, as well as by parasite infestation. Iron deficiency may occur in calves, lambs or pigs on low levels of nutrition. Generally, this is not a serious problem because of the liberal quantities of iron in nearly all natural feedstuffs, including mature grasses. But there is some indication that iron deficiency may be a problem in India, where animals are fed on straw for long periods. Supplemental iron has reduced weight losses in the early weeks of lactation in mature cows, and produced slightly more rapid gains in suckling calves, but no response has been reported in fattening cattle.

Manganese deficiency is unlikely to occur in ruminants under usual conditions, although deficiency symptoms—leg deformities, poor growth and body development in calves, and reduced fertility and frequent abortion in cows—have been reported when cattle were grazing pastures on sand and peat soils.

Cobalt deficient areas have been identified in Australia, U.S., Canada, and elsewhere; but few areas of the N-S 30° latitudes have as yet been identified as posing problems of cobalt deficiencies. There are, however, portions of Florida where cobalt deficiency is a serious problem in grazing cattle as evidenced by anemia, loss of appetite, retarded growth and general emaciation. It is reported that pastures in Uganda are deficient in cobalt for lactating dairy cows but not for other cattle or sheep. It may be that with improved feeding other areas will be identified as being cobalt deficient.

Under grazing conditions, parakeratotic-like lesions may occur in cattle that respond to oral and injected zinc supplement. Zinc supplementation has not been considered for cattle on good levels of feeding. Some evidence of response of cattle to zinc was reported from Guyana, but in general no significant effect on weight gains, feed

intake, or feed conversion have been reported for cattle and sheep on grazing, even when forage was sparse, except for a few isolated areas Preliminary observations from Puerto Rico indicate that grasses receiving heavy application of fertilizer may not provide sufficient zinc for good gains or milk yield, so the expanded use of fertilizer on some soils may necessitate zinc supplementation for good animal performance

The significance of iodine deficiency as a factor limiting performance in livestock is confined to specific areas, where it appears as an endemic disorder Where protein in the diet is near adequate, there should be no problem, except in areas with serious deficiencies in the soil

It is beginning to be recognized that pastures have inadequate sodium to provide the requirements for lactating cows and sheep, but as yet no seriously deficient areas have been identified

Isolated incidences of deficiencies of several other minor elements have been suspected in the N-S 30° latitudes For example, apparent selenium deficiencies in cattle and sheep were observed in Florida, but when selenate injections were made there was no significant increase in weaning weight of calves from cows injected nor was there a growth response in sheep There is also evidence that some minor element deficiencies may occur as the result of using certain by-products in concentrate rations, such as Cassava meal (See Chapter 7)

As a rule cattle and sheep receive all the vitamins they require under average feeding conditions, although deficiencies of vitamin A occur on rations of dry straw In addition, ruminants have a remarkable capacity for synthesizing most of these compounds in their digestive systems Once the rumen is developed, the only dietary vitamins needed are the fat solubles, A, D, and E In the past, vitamin A deficiency in cattle was confined to arid or semi-arid areas and to animals grazing during prolonged droughts But recent observation suggests that conditions may exist in which feedlot cattle show classical symptoms of vitamin A deficiency even though the carotene level of the ration may be well above recognized requirements

In finishing rations, devoid of hay, positive live weight gain response has been reported with vitamin E and K supplementation, but vitamin E alone seems to have no consistent effect on grazing animals Dietary requirements for B vitamins have been demonstrated experimentally during the first weeks of life prior to the development of the rumen These requirements are adequately met by the milk supplied to the calf or lamb at that time At later ages, it is well estab-

lished that these vitamins are synthesized in sufficient quantities under most feeding regimes by rumen bacterial fermentation, so that no dietary supplies need to be given ruminants. Vitamin D does not seem to be a recognized problem for livestock in tropical areas because of the general availability of sunshine.

Faulty mineral and vitamin interrelations in the feedstuff may be a significant factor in the performance of livestock in warm climates; but inadequacies of energy mask identification of the problems. As improved feeding regimes are implemented, no doubt deficiencies of minerals and vitamins will become important considerations. Currently, the major aspect to keep in mind in planning feed resources is the adequacy of the calcium-phosphorus ratio. If there is doubt about adequacy of minerals, multi-element mixtures are recommended. But providing supplements sometimes creates management problems, as is shown in Chapter 14. This summation of mineral and vitamin deficiencies is sketchy because the information is of this nature. Good livestockmen should, however, become familiar with the general recommended requirements and symptoms of deficiencies by referring to standard texts, such as that by Maynard and Loosli (1969), or the National Research Council and Agricultural Experiment Station bulletins on nutrient requirements of domestic animals, such as that by Smith and Loosli (1970).

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7

Concentrates, Feed Supplements, Feed Additives, and Other Feed Supplies

Often it is not economically feasible to provide significant improvements in forage production such as suggested in the previous chapter. Pastures, even when well managed, more often than not fail to yield adequate supplies of protein—especially for young, growing livestock—if the sole forages are grasses. The best sustained rates of gain for cattle on grass alone average no more than 0.5 kg per day. When gains are this low for cattle of 350 kg body weight or larger, the major portion of the energy from forages is used for maintenance. It then becomes desirable from an economic standpoint to provide animals rations having a higher energy content than is possible on grass alone. Development of feed supplies in addition to grazing is important as sources of both supplementary feeds for ruminants, and feeds for nonruminants, as well as to help make the most efficient use of the grass resources. If the animals lose weight or make no gains on the grazing, the grass is a lost resource.

Feedstuffs other than forages are generally classed as concentrates. These include by-products from plant and animal sources, synthetic supplements and waste products, as well as cereal grains,

TABLE 7.1
Composition of some animal and plant by-products available in various areas

Feedstuff	Dry matter	Dig crude protein	TDN*	Calcium	Phosphorus
	%				
HIGH PROTEIN FEEDS					
Blood meal, dried	89.5	72.7	60.0	0.32	0.25
Bone meal, steamed	87.9	26.2	65.0	30.53	10.02
Brewers grain dry	90.1	16.0	60.6	0.27	0.45
Brewers' grain, wet	23.7	4.2	15.7	0.07	0.12
Copra meal	86.6	20.6	69.0	0.08	0.67
Corn gluten feed	89.3	24.6	79.4	0.41	0.80
Cottonseed cake	89.1	17.2	48.9	0.23	1.12
Cottonseed meal	90.5	31.1	79.2	0.17	0.58
Fish meal (tuna)	90.1	44.3	60.5	3.89	2.89
Kapok meal, 30% protein	87.0	27.2	56.6	0.30	0.28
Meat and bone scraps	91.8	46.3	64.5	10.44	4.89
Peanut oil meal, 39% protein	90.2	36.7	80.3	0.14	0.50
Peanut screenings	92.0	19.0	70.1	1.18	0.05
Pulses	90.4	18.0	60.3	0.12	0.34
Sesame oil meal	93.7	42.4	71.3	2.01	1.59
Tankage	89.3	46.4	64.2	6.40	3.13
Yeast, dried	91.7	50.2	75.1	0.11	1.44
HIGH-CARBOHYDRATE FEEDS					
Banana, whole, dried	88.5	6.6	55.8	1.01	0.22
Banana, ripe, unpeeled	24.4	3.7	15.4	0.81	0.26
Cassava roots, dried	94.4	2.8	75.0	0.02	0.03
Cassava roots, wet, whole	31.9	1.7	25.8	0.01	0.04
Citrus pulp, dried	90.0	5.6	75.0	2.00	0.14
Cocoa pod meal	96.0	9.0	60.7	2.64	0.17
Coffee pulp, dried	92.0	8.4	29.0	0.20	0.13
Corn bran	90.5	5.6	49.8	0.04	0.14
Cottonseed, whole	92.5	10.7	75.8	0.24	0.68
Date stone meal	93.8	6.3	68.2	0.19	0.54
Maize	88.1	7.3	82.4	0.07	0.40
Manure, cow, dried	94.0	12.2	—	—	2.40
Molasses, sugarcane	79.7	1.1	60.5	0.83	0.09
Pineapple bran (dried pulp)	84.5	0.6	63.0	0.28	0.08
Plantain, ripe, unpeeled	27.4	4.1	60.4	0.92	0.26
Rice bran	90.1	6.5	55.1	0.11	0.65
Sorghum, grain	89.6	8.4	78.4	0.02	0.32
Sweet potato meal	90.2	1.3	72.7	0.14	0.12
Wheat bran	89.0	13.0	63.0	0.13	1.27
Yam, yellow, tuber, unpeeled	24.1	3.7	20.8	0.14	0.10

TABLE 7.1 (con't)

Feedstuff	*Dry matter*	*Dig. crude protein*	*TDN*[a]	*Calcium*	*Phosphorus*
			%		
	ROUGHAGES				
Berseem, hay	82.1	10.3	54.4	1.66	0.33
Corn cobs, ground	90.4	0.0	45.7	0.10	0.03
Corn fodder, green	24.1	1.5	15.3	0.17	0.09
Corn stalks	92.3	1.7	39.9	0.30	0.21
Corn silage, dough stage	22.2	1.1	15.5	0.11	0.07
Cottonseed hulls	88.4	0.3	38.1	0.13	0.07
Paddy straw	91.0	0.2	21.6	0.32	0.09
Peanut shells	92.3	1.6	19.0	0.23	0.04
Rice hulls	92.0	0.8	15.0	0.09	0.06
Rice straw	91.5	0.1	44.7	0.20	0.08
Sorghum fodder, dry	88.2	2.2	54.4	0.29	0.15
Sugarcane tops, green	26.4	0.6	14.9	0.10	0.07
Sugarcane bagasse, dried, ground	90.0	0.1	41.0	–	–
Sugarcane bagasse, fresh	60.2	0.0	20.6	–	–
Wheat straw	90.6	0.5	43.1	0.15	0.07
Yam vines, green	21.9	1.8	12.3	0.17	0.04

Source: Adapted from DeAlba, 1958; NRC, 1964, Oyenuga, 1959; Schneider, 1947, and various agriculture experiment station reports.
[a]Total digestible nutrients.

oil seeds, sorghum, and milo grain. The latter are the major suppliers of energy and protein for much of the livestock kept in the temperate zones. But in the tropics they are generally too costly for animal feeds because they are also the main foods for human consumption. By-products from plant and animal sources are the residues or wastes from the processing of food for human consumption. The most widely utilized products of this nature are rice bran; seed oil meals like copra, sesame, peanut, cotton, and soybean; molasses; and bone meal. A number of the synthetics are relatively new to livestock feeding, such as nonprotein nitrogen compounds, vitamins, and stimulants, including hormones and other additives. There is sometimes a fine line of distinction between by-products and waste products. Wastes generally refer to animal excreta, although the term may be applied to vegetable and fruit pulps from processing industries. There are additional products, which do not fit readily any of the categories listed, that have been employed as animal or human foods—e.g., algae, yeast, and seaweed. Other feedstuffs, such as new or modified products created by mechanical, chemical, or microbial treatments of some relatively common products, have proven useful too.

In general in many tropical areas, inefficient use is being made of the nutrients from the sources enumerated If new enterprises could be initiated to develop some or all of these materials, no doubt many of the existing deficiencies in livestock feeding could be alleviated

When an outsider first arrives in a local area, his initial question is, 'Why is not more efficient use being made of plant residues or by-products from food processing"? The answer is often, "the products are already being used" or "technology and machinery are needed to process the by product before it can be used effectively " The latter is usually the main problem On small farms any product not con sumed by the people generally goes for livestock feed, whether it be the chaff and straw from cereal grain harvest, corn stalks, the weeds and grasses from among the crops, or surplus fruits and vegetables Many households may have one or two fruit trees that do not produce on a large enough scale to merit processing, but without removal of some of the water, the fruit does not make very satisfactory feed Processing to increase the dry matter content is often the main factor determining usefulness of locally available materials

By products of tropical fruits or cereal grains are used as feeds most intensively where crops and livestock exist in a highly competitive situation An example is the proximity, in Florida, of the citrus industry and intensive livestock operations The by products of citrus are offered as an economic alternative to other feeds Dried citrus pulp is also shipped for use in other areas By contrast, the molasses from sugarcane and the seed from cotton, which are produced on small farms in tropical areas and brought to centers for processing, become available for commercial use particularly as exports to earn foreign exchange Like forages in the warm climates, by products have great potential, but livestock producers and governmental agencies will have to give them more attention and provide more resources before they become significant segments of the feed supply

The following sections describe several of the plant and animal by products, and fruits, that have been used as supplementary sources of protein and energy or as roughages, and suggest other possible sources The nutritive value and mineral content of some of these products is given in Table 7 1

PLANT BY-PRODUCTS

Sugarcane Bagasse

Bagasse is the fibrous residue of sugarcane stalks after the juice has been pressed out. It is composed of the hard, strong fibers of the

outer cortex and inner pitch of the cane stalk. When fresh, it contains 40–50% dry matter and a small percentage of residual sugar (about 0.3%). Because of the high lignin content of the stem, its utilization by nonruminants is limited. The pith which is high in cellulose can be used well by ruminants; but by weight the pith makes up only 10–15% of the bagasse. The pith is also highly absorbent. In the U.S., bagasse is used primarily as litter or bedding for livestock and poultry and as raw material in the manufacture of paper and other products. Since it has a rather high water content in the fresh state (40–50%), there are problems of storage unless it is dried. In fresh or dried form bagasse may best serve as a roughage, especially for complete pelleted rations. Grinding seems to improve palatibility. At present, its energy value should not be counted on. However, it may eventually be improved by alkali treatment. (See the section in this chapter on chemical treatment.)

In Puerto Rico (Randel, 1969), a ration containing 25% bagasse and 25% cane molasses, along with cereal grains, urea, and fish meal, has been recommended for lactating dairy cows, although rations containing 35% bagasse have been used satisfactorily for both lactating cows and growing heifers. From this series of experiments, it was concluded that bagasse could serve as the sole source of roughage. Its absorbent qualities also make possible a greater utilization of molasses than is usual in rations with silage and concentrates; its apparent restrictions on rate of intake help to reduce the tendency for diarrhea from high levels of molasses feeding. In Florida experiments (Kirk *et al.*, 1956), 50% of the hay in the feed of fattening steers was successfully replaced with bagasse. But there is other evidence that high levels of bagasse feeding (up to 25% of the ration) are undesirable in warm climates because the animal uses more energy to process the bagasse than it yields. The high heat of digestion increases the animal's heat load.

Sugarcane Tops

Sugarcane tops, which include the growing point, a few of the upper nodes, and accompanying leaves, are removed as surplus material. On large farms the tops and dry leaves are burned off before the cane is cut, while on small farms the tops are cut for livestock feed. Occasionally, the tops are dried and saved for feeding in the dry season. During extended dry periods, the whole plant may be used as fodder, but when the cane is mature the stem or stalk is not very palatable. The feeding value of cane tops is rather low: 0.5–1.5% crude protein, 0.5% fat, and 9% crude fiber (Table 7.1). But tops can

serve as a roughage if used in conjunction with concentrates In South Africa, cattle fed 6–7 kg of sugarcane tops per 100 kg live weight, along with peanut meal, gained 0 6 kg per day (Lishman, 1964) And in Florida, tops fed ad libitum in combination with protein and mineral supplements were deemed satisfactory for fattening beef cattle (Bregger and Kidder, 1959) Fattening steers also did well in the Philippines when fed three parts concentrates to one part sugarcane tops Cane tops have been used with partial success as silage, but whole cane plant silage has proven more valuable Still, the problem of harvesting and the tendency of cane silage to cause diarrhea in animals make it less satisfactory than corn silage

Corn Products

Although the whole corn kernels are used for livestock feed in many areas, certain residues and by-products are also good feeds The by product from the production of glucose and starch, corn gluten feed, is an excellent source of protein It is a common constituent of poultry, swine, and dairy cattle concentrate mixtures In the Philippines, concentrates with 33% corn gluten feed were equal to an equivalent amount of corn for lactating cows

Corn bran, the by product from the preparation of corn meal for food, is composed of the outer covering of the grain, tip cap, and fragments of the endosperm Some brans are coarse and others fine, depending on the grinding process The coarse type is slightly higher in protein, fat, and fiber In rural areas, swine are frequently fed the bran from home preparations of corn products Several Latin American countries, e g , Venezuela, have developed extensive swine and poultry industries dependent on extensive use of corn bran and corn gluten feed

Corn cobs, husks, and stovers are low quality roughages, yet in combination with molasses and urea they make acceptable rations for maintaining adult cattle or sheep during periods of short supply of feed Many small farmers soak the husks, cobs, or stovers in water to aid their acceptance by the animals Rations of ground corn cobs, molasses, and copra or soybean meal in the ratio of 75 15 10 have been recommended for buffaloes and cattle in India and the Philippines

Cacao Pod Meal

Cacao pod meal has been used with mixed results In Florida tests, 50% dried cacao pod meal was 96% as good as rations con-

taining an equivalent amount of corn (Haines and Echeverria, 1955). There were no problems of flavor in the milk of cows fed the 50% cacao pod meal. In Costa Rica, results were less promising. A level of 50% cacao pod meal in both low and high fiber rice bran diets fed growing heifers lowered digestibility of all nutrients; and at a 60% level, 10.2 kg of dry matter were required per kg of gain—nearly 30% more feed than was required in the control diet of cereal grains. The lowered efficiency of the cacao meal ration was attributed to the high calcium content resulting from soaking the pods in lime solution before drying and chopping (Bateman and Larragan, 1966). The contrasts in findings could be due to differences in the manner of preparation and perhaps, partially, the size and age of animals.

Although there have been some reports of toxic substances in cacao meal and ground cacao shells, problems with cattle have not been serious. The use of the meal for poultry and swine rations is recommended with reservations, even though satisfactory performance has been obtained in several swine feeding tests.

Coffee Meal, Pulp, and Hulls

Various tests have been made in Colombia to determine the value of feeding coffee meal (ground beans after extraction of oil) to dairy heifers. The heifers were fed 3 kg of grain mixtures per day containing from 0 to 98% coffee meal. They consumed all the feed offered in the rations containing less than 25% coffee meal, but only 29% of a ration containing 98% coffee meal. The differences indicate that palatability was a problem. The gains on the 25% level were nearly equal to those from the control ration of cereal grains. Although coffee meal is rather high in protein (17.4%), it does not lend itself to more than a partial protein substitute due to poor animal acceptance.

Experiments with coffee pulp (the outer covering of the coffee berry) in Puerto Rico suggest that the wet pulp has good nutrient qualities because of its sugar content, but that the sun-dried pulp is not a high quality feed because of the loss of sugars in soaking to loosen the pulp from the green bean after picking. Another problem is getting sufficient quantities of the pulp for feed since the pulp is normally removed on the farm a few hours after picking; therefore, available in small amounts only on days of picking.

Dried coffee hulls (the outer shell, right around the beans) are available at processing centers. But like rice hulls, they seem to be relatively indigestible woody materials. On a dry matter basis, total cell wall is 91.0%, total crude lignin 19.7%, cellulose 49.0%, and hemicellulose 22.1%. The estimated apparent digestibility of coffee

hulls is near zero Due to the very high lignin content, coffee hulls should be regarded strictly as a diluent in any ration There may be value at times in putting inert sources of fiber in some high concentrate rations for fattening cattle or lambs, but in dairy cattle feeding, where energy intake is the limiting problem, coffee hulls would serve no useful purpose

Copra Cake

Copra cakes or coconut oil meal, is a by-product of the coconut oil industry It is medium in protein, high in TDN (Table 7 1), and may be used in rations for all classes of livestock It may depress to some degree the feed efficiency and alter carcass quality in swine, however Carcasses of pigs fed coconut meal had less fat on the shoulders and smaller loin eye area than those of pigs on a soybean supplement (Grieve *et al* , 1966) In Hawaii, coconut meal has been used quite successfully as the main protein component of rations for dairy cows Elsewhere, up to 40% has been used in poultry rations without problems of toxicity or palatability The main limitation of coconut cake is the high fat content, which is conducive to rancidity and rapid spoilage in warm climates The protein in coconuts is also very sensitive to heat. If the heat is not properly regulated during processing, the quality of the protein may be lowered to the point where copra cake becomes almost worthless as a feed for all livestock This often happens where processing is not well controlled

Molasses

Molasses is the most abundant and extensively used by-product in warm climates It is generally an excellent source of carbohydrate, but varies to some extent in quality due to the water content and amount of contaminants (mainly soil, where the cane is not washed before grinding) The major source of molasses is sugarcane, but in certain areas there are significant quantities produced from citrus and pineapples It is fed to cattle and sheep as a lick, sprayed or poured over other feedstuffs (e g , dry straw or green chop), mixed into prepared concentrates, or heavily diluted with water and offered as the main source of free water Unless it is mixed with highly absorbent materials, such as bagasse, it is recommended that molasses not exceed 7–10% of the concentrate or 3–5% of the volume or weight of the total ration With a highly absorbent material, molasses may

make up to 40% of the total ration without harmful effects. In addition to the advantages of abundancy, good energy content, and palatability, molasses stores reasonably well. These factors make it one of the best feeds in the tropics.

Molasses is not used extensively in swine and poultry rations because it causes the ration to have excess magnesium and to be deficient in phosphorus which tends to cause diarrhea in these animals. Nonetheless, molasses up to a level of 30% of the total ration has been used without serious ill effects for poultry feeding in Puerto Rico and Colombia.

Date Stone Meal

In Egypt there are over 30,000 tons of date stones produced annually. The ground meal is medium in fiber content (17.6%) and fat (7.5%), but low in protein (6.3%); still, it is a good source of energy. Growing lambs given a mixture of date stone meal, urea, and undecorticated cottonseed cake showed daily gains similar to those of lambs given rice bran and cottonseed cake. Date stone meal has also been used successfully as a replacement for 10% of the barley in chick rations. This product is not widely produced but should prove quite useful at least in areas of production.

Peanut Meal

Peanut meal (ground nut meal) is an excellent source of protein. In India and Pakistan it has proven superior to copra meal as a source of protein for ruminants. However, there have been reports of toxicity from afflatoxins produced by molding due to inappropriate storage in India, Britain, South Africa, and elsewhere. Even so, the production of peanuts might well be expanded to serve as a source of oil for human use and protein supplement for all classes of livestock.

Rice Products—Bran, Hulls, and Straw

Rice bran is a popular feed in rural rice producing areas. It is produced in rice mills or in households by pounding with mortar and pestle to separate the polished rice from the bran and hulls. The quality of bran is influenced by the milling process and the type of rice used. Non-glutinous varieties provide brans of better feeding

value than glutinous varieties Commercial products may be coarse or find depending on the screening and grinding processes Rice bran is a good source of energy for livestock, but it should not exceed 50% of the ration for poultry or swine

Rice hulls are a very low quality roughage They have a high lignin content with an estimated digestibility of near zero Their main use is as a "filler" in commercial concentrate mixtures. Rice straw is a fair quality roughage Most of the straw is fed on the farms during the dry season with some augmentation by rice bran This type of mixture is deficient in protein as well as calcium and phosphorus for sheep or cattle In India and the Philippines, the current recommendation is to use rice straw plus molasses and copra meal as a ration for lactating cattle and buffaloes and also for draft bullocks

Wheat By-products— Bran, Screenings and Straw

Wheat bran, a by-product of the flour industry, is an excellent feed for all classes of livestock It is medium in protein content and high in energy (Table 7 1) Like rice bran, wheat bran is fed even in rural areas and this is the main disposition of the straw Wheat straw is a somewhat better feed than rice straw because of higher contents of calcium and phosphorus Still, it is a low quality roughage and needs supplementation with other sources of energy and protein During extremely hot weather it remains questionable whether the animal obtains much benefit from the feeding of straw due to the high heat of digestion For this reason the feeding of straw should probably be relegated, insofar as possible, to the cooler seasons for maximum benefits to ruminants

Numerous other plant by products have been used on a limited basis and with varying degrees of success For instance, kapok meal has been employed successfully as a protein supplement for cattle in Nigeria (Oyenuga, 1959)

ANIMAL BY-PRODUCTS

The most popular feed products from the preparation of meat and fish for human use are blood, bone and fish meals, and meat scrap These are excellent sources of protein, and bone meal is an especially good source of calcium and phosphorus Since these by-products are produced mainly in slaughterhouses or processing plants in urban

centers, and not in large quantities, their use in rural areas is very limited. In most countries, blood and fish meal go into commercially prepared poultry and swine rations. Bone meal gets somewhat wider use since it is frequently sought as a mineral supplement for grazing cattle. Bone meal plus salt will generally suffice as an appropriate mineral supplement for grazing cattle or sheep.

Any by-product from animals must have proper heat treatment to eliminate the risk of disease. Since precautions have often been inadequate, acceptance of bone meal and other animal by-products may be low among animal producers.

FRUIT BY-PRODUCTS

There are tremendous quantities of fruit produced in the tropics, much of which goes unused. Except for citrus and pineapple, little use is made of the by-products or wastes, primarily because of lack of uniform supplies and the medium to low feeding value, high water content, bulkiness, and rapid deterioration of these fruits following harvest. Fruit by-products are feasible for livestock feeding primarily around processing plants.

Bananas

Dried, whole ripe, and whole green bananas have been used quite successfully for swine feeding in certain areas of Latin America (Maner *et al.*, 1966). Dried bananas were equal to cassava meal and corn when supplemented with adequate protein. The rate of gain of pigs with ad libitum feeding of green and ripe bananas was less than for the dried product due to the moisture content. Ripe bananas were better than green ones as a consequence of their higher sucrose content. When pigs were fed enough ripe bananas that they did not need to consume the peelings, gains were only slightly below those from whole dried bananas. Green banana leaves have proven as good as chopped napier grass for feeding cattle. The chief limitation of banana fruits, stems, and leaves is the high cost of dehydration to provide a product that can be stored more than a few hours or days. In the unprocessed state spoilage of all but the stem is rapid. The usefulness of bananas in commercial operations appears to be restricted to large marketing areas and areas where harvest is almost continuous, such as near Guayaquil, Ecuador.

Citrus Pulp

Citrus pulp is the residue from the processing of citrus fruit into juices and canned fruit After extraction of the fruit or juice, lime water is added to reduce acidity, and the pulp and peelings are then dried Citrus molasses may be extracted from the pulp and oil from the seed as is the common practice for processing plants in Florida, but elsewhere citrus pulp represents the whole by-product Some plants produce citrus meal, which consists of the fine screenings from pressed and dried citrus residue and citrus seed meal The flavor of citrus pulp varies according to the major fruit used Grapefruit pulp seems most palatable to cattle

Citrus pulp is an excellent feed (Table 7 1) It has been used quite effectively to make up to 65% of the total ration for fattening cattle (Cunha and Rhodes, 1966) and up to 35% of the concentrate mixture for lactating cows Finely ground pulp, citrus meal, or seed meal may constitute significant proportions of poultry and swine rations Cull citrus fruits, fed whole, have met with only partial success Tangerines fed to swine gave poor results, yet cull grapefruit was a good winter supplement and could supply 30–50% of the energy for fattening cattle (Kirk and Davis, 1954) In view of the excellent success of citrus products in the U S , it seems that other countries should consider investments in processing industries—not only to supplement cattle feed, but also to provide more variety in products intended for human consumption

Pineapple By products—Bran, Pulp, Molasses, Stump Meal, Hay, And Silage

The most efficient use of pineapple by products is in the live stock industries of Hawaii Pineapple bran (dried residue from the canning industry), pineapple molasses, hay, and silage are highly acceptable for lactating dairy cattle (Otagaki *et al* , 1960) Pineapple bran has also given good results in poultry and swine rations Fresh pineapple pulp may be fed to lactating cows and steers Its acceptability is good if fed within a few hours after leaving the processing plant. However, its protein content is low, consequently, it must be supplemented with a good source of protein Several dairy operators in Puerto Rico obtain reasonably good levels of milk yield during 8 months of the year when the fresh pulp is available by feeding the pulp ad libitum with a 24% crude protein feed Green chopping of the plant after fruit harvest provides good roughage for cattle on fattening rations

VEGETABLE BY-PRODUCTS

In the temperate zones, the by-products of the vegetable processing industry are used widely for silage, but currently there is little use of vegetable wastes for livestock feeds in the N-S 30° latitudes. The reasons are similar to those limiting the use of fruit crops, namely perishability, small farm production, and lack of processing industries. Neverthelsss, in the rural areas of densely populated countries intensive use is made of vegetable crop residues for livestock feeding. The leaves and stalks of vegetables are often rich in minerals and reasonably good in protein and carbohydrates, but they are only fair in feeding value unless dehydrated. Sun drying markedly reduces their value as a source of vitamin A due to a breakdown in carotene by respiration. This means that except in rural areas vegetable residues will probably continue to be insignificant sources of feed.

OTHER PRODUCTS

There are a number of other products produced basically for human consumption that have also been fed to livestock, such as cassava, and other products which might be given more attention for livestock feeding.

Cassava

Cassava (yucca in Latin America) is a basic food crop in many areas of the warm climates since it is an excellent source of carbohydrates. There are numerous varieties (about 80). The yields of many varieties are as high as 20–40 metric tons per hectare (some have yielded over 100 tons of fresh tubers per hectare). Yields are determined by variety, soil fertility, and climatic conditions. Cassava responds well to fertilizer and propagates easily. Some varieties reach maturity at 6 months and others at 16–20 months.

Europe is presently importing over 30 million tons of cassava meal annually, mainly from Africa, for use as a carbohydrate source in swine rations, although also for use in poultry and cattle feeding. Molding, heating, and sweating during transport present problems yet to be solved. Still, it appears that cassava may be one of the most extensively produced tropical crops in the future.

All varieties of cassava contain hydrocyanic acid (HCN) in varying

amounts And even small quantities of HCN have severe effects on the growth and health of pigs and poultry Cassava varieties are generally grouped as edible or nonedible The edible varieties contain about 0 05% HCN in the skin, 0 03% in the flesh, and 0 005% in the leaves (Adriano *et al*, 1932) Varieties considered poisonous contain much higher HCN levels in the flesh Edible varieties vary in fiber content of the flesh, hence differ somewhat in feeding value The HCN is water soluble, so cooking reduces the chances of toxicity Cassava tubers are about 81% edible Freshly dug tubers must be cooked and chopped into small pieces and dried for storage or they will spoil in about 3 weeks

A swine operation of about 10,000 head in the Philippines allows the animals to root up cassava tubers In drylot feeding, three parts of raw cassava have been used to replace one part of dry concentrate Tests in Colombia showed that chopped cassava, in combination with a well fortified protein supplement, could serve as the main energy source in growing finishing swine rations However, young pigs tend to overeat protein supplement to satisfy dry matter and energy needs until their stomachs are large enough to permit consumption of greater quantities of fresh cassava Older pigs are able to consume sufficient cassava to satisfy their daily energy needs and eat only enough supplement to meet their requirements for proteins and vitamins The feeding value of dried cassava is about 95% that of corn when used as 15% of the ration for 10–20 week old pigs, 20% for 20–30 week old pigs, and 25% for 30–40 week old pigs (Asico, 1941)

The dusty powdery nature of dry ground cassava can restrict acceptability The low protein and vitamin content of most varieties requires that special care be given to proper supplementation Also, cassava is almost void of fats or oils, hence small quantities of these will improve performance (Maner *et al*, 1965) Although most varieties of cassava are low in protein (1–3%), one variety in Colombia, Llanera, has a protein content of 7 25% on a dry weight basis It has produced yields of 78 tons per hectare in 10 months The fact that some varieties offer possibilities as being adequate or nearly so in protein content is of tremendous practical significance

Cassava refuse meal, a by-product in the manufacture of starch, has also been used in animal rations Reports from the Philippines (Castillo *et al*, 1964) suggest the possibility of making cassava silage from chopped, freshly dug tubers Although cassava leaves are high in protein, they have not been widely used because removal of the leaves restricts development of the tubers, and the leaves are low in dry matter during the growing stage

Sweet Potatoes and Yams

Sweet potatoes and yams are also starchy tubers widely grown in tropical areas. In contrast to cassava, there is much less problem of toxicity in these species. Otherwise, they are much like cassava in respect to production methods, yields of improved varieties, and value as a carbohydrate source in feeds. In the future the production of these crops, using improved varieties, will no doubt expand rapidly.

Cottonseed Cake and Meal

Cottonseed cake and meal are typically by-products of the textile and edible oil industries. They are included in this section because several countries are expanding their production of cotton with emphasis on the production of edible oil and protein supplements for livestock—even though the cotton fiber may be sold on the world market at a loss. In several tropical countries, the oil is extracted from the seed by the hydraulic method (pressure alone) with the resulting cake consisting of hulls and meal. This product, by volume, has a considerably lower feeding value than the cake or meal produced from the expeller process (solvent extraction) used in the U.S.

Either meal or cake may serve as the chief protein sources for all classes of livestock, although the value of cottonseed by-products for swine and poultry is less than that of soybean, peanut, or copra meals because of the rather low lysine content of cottonseed. For poultry and swine, supplements of fish meal, soybean meal, or meat scrap are also needed. These combinations improve protein quality and prevent toxicity from gossypol. Extensive experiments have proved that cattle and sheep over 4 months of age may be safely fed cottonseed meal as the main source of protein. About 1 kg or slightly less per head per day is frequently sufficient protein supplement to carry adult cattle through the dry season if they are on fair grazing. Except at very high levels of feeding, gossypol is not toxic to cattle, but the meal must be degossypolized to 0.04% or less to be used extensively in swine or poultry rations. Besides being high in protein, cottonseed meal is a good source of phosphorous; but it is low in calcium.

Cottonseed cake—the type including hulls—is a reasonably good feed; however, because of its high fat content it will not store in the tropics. Rancid cake has caused death on many occasions among cattle and sheep in India. As with several other feed resources in the

tropics, better handling arrangements are needed to make cottonseed products as useful as they should be

Leguminous and Non-leguminous Leaf Meals

Good quality leaf meal from forages and trees can serve as a source of carotene and protein Mature, green leaves contain more carotene than young leaves The carotene is lost in storage, but antioxidants help in minimizing the loss Extensive experiments, including those in India, Hawaii, and Guatemala, have shown that leaf meals could be used at levels from 3 to 5% in livestock rations Higher levels appeared to depress growth rates of poultry.

Legume leaf meals, such as alfalfa, are accepted and commercially available, but as indicated in Chapter 6 the limited culture of alfalfa and other legumes in the tropics makes current production of leguminous meals very low Seemingly, the production of meals could be a further incentive for development of legumes in the tropics

Although the nutritive value of the leaves of cassava, sweet potatoes, yams, bananas, and plantains is good, it is unlikely that commercial processing will develop due to the great amount of labor required, fluctuating supplies, and the high cost of dehydration However, some industrial processing may prove feasible in certain locations to support poultry or swine industries

Water Hyacinth (Enhhornia crassipes)

The water hyacinth is a common weed in lakes and rivers in tropical areas, often impeding the flow of water and obstructing waterborne traffic Silage from this plant is palatable but low in digestible protein (0 4%) and total digestible nutrients (4 7%) (Loosli *et al*, 1954) Given its low energy value, the consensus is that preparing silage is not worthwhile unless other feeds are very scarce or expensive

Seaweed and Unicellular Algae

Seaweed and algae are often spoken of as having high potential as nutrient sources for both man and animals, but as yet little use has been made of them It has been suggested that certain types of algae

could be used beneficially at levels of 10–20% of the diet for pigs, sheep, and cattle, and that seaweed could serve as a source of minerals. But further development of technology seems necessary before expansion of these sources can become economically feasible.

Yeast

The picture is somewhat different for yeast as it is already widely produced from molasses or other products and used in foods and feeds. Recently, in Europe, commercial production of yeast and bacteria has been initiated using normal paraffins from the petroleum industry. Cost in relation to other feed resources is a major problem. Cost-return studies made in Latin America (Feldman, 1969) indicate that the prospective market in a single country would not support an economical yeast producing plant. Nevertheless, since the yeast and bacteria that can be produced from hydrocarbons are sources of high quality protein, some countries may be willing to provide the subsidy necessary for plant construction within their boundaries, or some regional arrangement may be made.

Fish Soluble Flour and Ethamol

Two other products worthy of mention as protein sources are fish soluble flour made from whole fish and the synthesized product ethamol. The former is a commercial product used in fortifying human diets and may be used similarly in some animal rations. The latter is a fermented product prepared in semiliquid form from fish soluble products and molasses. This product is currently in commercial production in Puerto Rico. A ration consisting of 30% ethamol, 35% bagasse, 30% ground corn, and 2% urea plus a mineral and vitamin supplement has been used successfully in Puerto Rico for fattening cattle (0.8 kg average daily gain) and for lactating dairy cows.

High-lysine Corn

Recent experiments in Colombia with corn containing the opaque-2 gene, which increases lysine content, showed that growing pigs gained 56% faster on a diet of opaque-2 corn and had a feed efficiency 28% higher than those fed normal corn (Gallo *et al.*, 1969).

In each case corn was the only source of protein in the diet In tests with fattening pigs, those fed a 10% protein diet of only opaque-2 corn made gains equal to those receiving a 16% protein diet consisting of normal corn plus soybean oil meal These preliminary results suggest great possibilities for improvement of protein supplies Production of opaque 2 corn has not caught on in the U S due to its lower yields, but with further development, there may be much greater use of this type of corn throughout the world

WASTE PRODUCTS

In this discussion, waste products consist of manures and creamery wastes that ordinarily have little utility, except to serve as a source of fuel or to enhance soil fertility

Whey

"Whey" is the term commonly employed to identify the residual liquid of milk from cheese making Cheese of some type is produced in almost all rural areas of the warm climates, whether it be by the nomadic tribes of Asia and Africa or the Indians of the Andes region of South America The whey contains the milk sugar, the albumin, and a large part of the ash Because of its high water content, it has less than 7% dry matter Nonetheless, it is widely used in rural areas for both human and animal consumption In large commercial cheese operations, the product is dried and used as a constituent of livestock rations, especially for poultry, swine, and young calves

In some places the liquid whey is set in the sun to partially evaporate the water and to ferment the whey Liquid whey mixed with chopped straw and rice or wheat brans has met with reasonable success for rearing calves in India, although the semi dehydrated form gives better results than fresh whey In Colombia, Venezuela, South Africa, and elsewhere, several successful swine operations have been established near commercial cheese factories The liquid whey is used as the sole source of liquid for the pigs, and replaces 10–15% of the total dry feed needed Brewery slop from the beer industry has likewise been useful in the feeding of swine and cattle Dried brewers grain, like whey, is a very nutritious feed product for livestock

Poultry Waste

Poultry litter, particularly from broiler production units, has become a cheap source of nitrogen for ruminants in parts of the U.S. Similar utilization may be possible in countries such as Jordan, Israel, and Venezuela, which have developed large poultry industries. Poultry droppings contain 60–90% of the urinary nitrogen as uric acid and 9–13% as ammonium salts. Uric acid can be utilized by rumen organisms; but it is unstable in wet droppings and changes rapidly to urea and ammonium salts. This means that the waste must be fed quickly or dried to preserve its value. The digestibility of the nitrogen in pure droppings ranges from 70–85%. Many factors, such as source of litter, (laying hens or broiler), type of litter used (corn cobs, wood shavings, rice hulls, bagasse, or straw), ventilation of the house, frequency of removal, quantity of litter in the droppings, and density of birds, can affect the chemical analysis and the quality of the product for feed usage.

Most experiments with poultry litter for ruminants have been with beef cattle, but some tests have been made with sheep and dairy cattle. Dried poultry litter has proven satisfactory for wintering beef cattle in the U.S. southwest. The cattle received 2–3 kg per day of 40% litter, 38% sorghum grains, 10% alfalfa meal, and 10% cane molasses. In other tests, cattle maintained body weight on 25% litter and grass hay. A period of adaptation to poultry litter may be necessary, but cattle or sheep consume it readily if it is mixed with a quantity of cereal grains or grain substitute (Brugman *et al.*, 1964). Both lactating cows and growing heifers will consume sufficient quantities of dried "pure" chicken manure, when added to low-nitrogen diets, to satisfy their nitrogen requirements. Some trials have also been conducted with cattle in India with acceptable results.

Poultry house waste serves its best purpose when ground and mixed thoroughly with a high energy feed. Vitamins A and D and phosphorus need to be included in the ration. Before feeding, the litter should be passed over a magnet to remove any fragments of metal. It should also be kept dry, as wet litter is not palatable. Diseases may sometimes be transmitted by poultry waste (especially tuberculosis), and there is also the danger of carryover of pesticide and antibiotic residues to the cattle. Because of these dangers, some countries have restricted the use of poultry waste; however the problems do not appear insurmountable.

Cow Manure

There is some evidence to indicate that the fecal residue from grain-fed cattle may be recycled through cattle to derive more than manure value from undigested feed and microbial residues In one experiment, beef steers consumed a feed mixture containing washed wet fecal residue in an amount equal to 40% by weight of the total ration They gained 1 4 kg per day and required about 700 kg of dry matter with 100 kg of gain (Anthony and Nix, 1962). Low-moisture silage with high nutritive value and excellent palatability has been made by combining feedlot manure and coastal bermuda grass hay. This silage served as the only feed for ewes for more than one year with good results as measured by lambing percentage

Although very little use has been made of cow manure, it appears that cattle operations—fattening or dairy—near urban centers could make effective use of their manure and simultaneously reduce problems of waste disposal Of course, there is the danger of spreading disease, and in many areas the manure is of equal or greater value for crop production

Obviously there are numerous natural and residue products other than forages that could be used to advantage for livestock feeding Some of these sources can be developed through increased labor intensity—e g , gathering and drying of plant leaves to aid in alleviating protein deficiency Also some of the coarser roughages could be used more effectively as carriers for molasses However, processing plants are required to reduce the moisture content of many materials for animal use and to permit storage This poses the question Should countries invest in programs to develop forage resources or allocate capital to processing industries that would supply feed? The best solution depends upon many factors But it could be argued that processing industries will develop slowly unless supported by government inputs of capital, whereas, the private sector is more likely to invest in forage production on its own

NONPROTEIN NITROGEN COMPOUNDS

Urea and other nonprotein nitrogen products (NPN) have been acclaimed by many as important potential sources of nitrogen, which may be utilized by ruminants to replace protein from cereal grains or

to make up deficiencies on grasslands. The concept of using NPN is not new. As early as 1891 it was suggested that rumen microflora were able to convert NPN into true protein. Since that time thousands of experiments have been conducted on the utilization of various sources of NPN. Many excellent reviews are available—e.g., Krebs (1937), Barnett and Reid (1961), Blackburn (1965), and Loosli and MacDonald (1968).

Numerous compounds have been tested as sources of NPN. These include ammonium acetate, bicarbonate, carbamate, and lactate, biuret, dicyanodiamide, glutamine, glycine, and urea. Of these, urea is currently the most widely used, as cost and availability impose limitations on the others.

Urea is both a natural and a synthesized NPN product; it occurs in plants and is a by-product of metabolism. The saliva of the cow contains a small amount of urea, which goes into the rumen along with that from the feeds. Urea dissolves and is hydrolyzed to ammonia by bacterial urease in the rumen. The ammonia can then be utilized by the rumen bacteria for synthesis of the amino acids required for their growth.

The primary justification for using synthetic urea supplementation is to provide a source of nutrients for the microflora to prevent their extracting nutrients from the feeds; the supplementation thereby lowers the cost of the total ration. There are, however, limitations in the needs of the microflora which means NPN compounds can be used efficiently only up to a point. When ammonia is produced more rapidly than needed in the rumen or when its concentration becomes too high, the excess is absorbed directly into the blood stream, reconverted to urea in the liver, and wasted by excretion through the urine. The animal's level of water intake, adaptation to urea, and nutrition level, as well as the nature of the feed ration, all influence the amount of urea that the animal can use effectively.

The addition of urea to the ration enables the livestockman to add protein equivalent without adding additional energy since urea contains no available energy although it is rich in nitrogen. The major disadvantages of urea are its low palatability and potential toxicity when fed at high levels. For these reasons it is generally recommended for cattle and sheep that urea should not exceed 1% of the total ration, be no more than 3% of the concentrate mixture, and constitute not more than one-third of the total protein equivalent in the ration. In actual quantities, this means that 0.2–0.5 kg of urea may be consumed daily by a cow, the range depending on the type of ration. In spite of these limitations, urea is already widely used with satisfactory results as a supplement in the temperate zones. Virtanen

(1966) reported yields of more than 4000 kg milk per year by cows in Finland fed diets in which urea and ammonium salts were the only sources of nitrogen In the tropical areas, however, the use of urea has been limited for several reasons, among which is the high incidence of toxicity when urea is given to animals on poor diets

In 1959 the estimated world production of urea was about 1 9 million metric tons, but output is expected to exceed 15 million tons by the early 1970s There are two grades of urea—fertilizer grade, which normally contains 46% nitrogen or 290% crude protein equivalent, and feed grade, which has 42–45% nitrogen or 262–281% crude protein equivalent Although feed grade is preferred, fertilizer grade may be used The fertilizer grade consists of larger particles, which create problems of distribution when mixed with concentrates, but this presents no serious difficulty when the urea is added to the plant materials at the time of ensiling However, another problem that may arise with fertilizer grade is the type of conditioner (anticaking materials) applied by the manufacturer Some of these may be toxic

Numerous trials have been conducted to determine the most effective way of incorporating urea into the animal ration Currently the more widely practical methods involve (1) combining urea with molasses and feeding the mixture as a lick, spraying it on standing grass or dry roughages, or mixing it with cereal grains, (2) making a gelatinized starch and urea mixture (commercial name, Starea), which can be fed as a supplement in concentrate mixtures, (3) making a pelleted combination of urea and alfalfa meal, such as Dehy-100, (4) adding urea to silage at time of ensiling, (5) adding urea to mineralized salt, bone meal, or other mineral supplements and feeding the mixture as a lick, and (6) replacing part of the protein rich source in a protein supplement mixture The most effective means of utilizing urea depends on a number of factors, especially cost and availability of other feedstuffs

Urea has been tested in various combinations with a large number of the available roughages, cereal grains, and by-product feeds The mixtures with high proportions of cereal grain have generally given good results In the U S and Britain, urea is at present a low cost nitrogen source compared to plant protein, and consequently a favorite of many producers for fattening cattle and dairy cattle rations There is no discrimination on the market against meat or milk from rations containing urea In some experiments, urea has given results equal to protein supplements from cereal grain sources, but the bulk of the data show urea to be slightly inferior for fattening cattle on high concentrate rations Results have been satisfactory when urea pro-

vided 25% of the nitrogen, but at higher levels palatability has been a problem. Many of the commercially mixed concentrate feeds given to dairy cattle in the U.S. now contain 20–35% of the nitrogen as urea, in place of soybean meal and other high protein feeds. This represents a substantial saving in feed costs. In Hawaii, urea plus soybean meal served as a supplement to a ration consisting of napier grass, 25% molasses, pineapple bran, and minerals. This ration gave milk yields only slightly lower than those from a conventional protein supplement but at a lower cost.

Supplementation of low quality dry pastures by spraying with a molasses-urea mixture is an attractive idea. This has been tried extensively in areas of South Africa and also in Oklahoma, but because it has not proved economically sound, it is rarely practiced by commercial operators. One reason that the molasses-sprayed grasses give poor returns compared to unsprayed grasses is that the molasses seems to affect the grazing preference of the animals, causing them to consume lower quality plant material than usual. The supplement must then compensate for the decreased intake of nutrients. Some encouraging results have been reported. In South Africa, sheep grazing dry summer pastures lost 24% of their body weight over a 3-month period; the use of pasture sprayed with a molasses-urea mixture reduced losses to 12%. But sheep given a grain supplement with or without urea lost only 4% of their body weight. In spite of some encouraging results, there does not yet seem to be sufficient evidence that spraying molasses-urea onto low quality pasture will give profitable results, although it could be an emergency measure during severe droughts.

The usual practice of providing grazing animals with salt licks has inspired development of formulations for giving cattle or sheep licks containing some supplementary urea. But there are at least three problems with these mixes: the problem of getting uniform daily consumption, the hazards of toxicity from over indulgence, and the tendency of the animals to restrict their range for grazing. A number of materials have been employed to increase or decrease the palatability of mixtures in order to ensure regularity in intake of urea. Some mixtures currently in use are the following: (1) blocks containing 33% urea and superphosphate; (2) blocks with 40% urea, 10% molasses, 47.5% salt, 2.5% sodium phosphate, and a trace of cobalt; (3) a mixture of 15% urea, 15% water, 10% superphosphate, 10% ground limestone, 10% bran, and 40% molasses; (4) a mixture of 10% urea, 30% wheat, and 30% distillers solubles; and (5) a mixture of 25–40% urea with molasses, salt, phosphate, cobalt, and copper. Trials with these and other

mixtures have, in general, given beneficial results as supplements for grazing animals, but most tests have been of short duration. Hence, the value of using this form of urea on a year-round basis is not clear

Corn silage can be supplemented by adding urea at the time of ensiling or at the time of feeding Either way the urea may lower the acceptability of the silage Adding at the time of ensiling has the advantages of reducing labor and lessening the danger of toxicity. The green chopped material should have a dry matter content in the range of 32–35%, otherwise, seepage losses will be high due to the high solubility of urea Adding 5 kg of urea per metric ton of green chopped material at 33% dry matter should increase the crude protein content of the silage approximately 1 3% on a wet basis, which could raise the total crude protein of the silage 40–50% depending on the material used The urea can be well distributed throughout the silo in a tower silo, but it is difficult to get uniform distribution in a horizontal silo unless filling is done by blower

In warm climates the appropriate time for silage making is during the rainy season At that time moisture conditions are such that it is very difficult to get the green material wilted to as much as 40% dry matter Under these circumstances it is more efficient to add the urea at the time of feeding Good quality grass silage, sprayed with a mixture of molasses and urea, has proven satisfactory for maintaining pregnant cows and for wintering growing cattle However, adding urea water solution alone to the silage before feeding has not proven very successful

Experiments have shown that urea treated corn silage placed in bunks for 6 hours during the summer changed from initial pH of 3 8 to 7 0, indicating volatilization of ammonia If urea treated silages are used in a warm climate, they should be rationed for rapid consumption so as to minimize losses from the high ambient temperatures

Urea-molasses mixtures, such as the commercial product Morea, have met with some success as a means of adding urea to the diet of cattle These mixtures are fed in an open trough or sprinkled over roughages If the urea molasses mixture is offered free choice to grazing animals, the intake of forage may decrease to the point that no net gain is realized, therefore, if the mixture is intended as a partial supplement, best results may be obtained by restricting intake On the other hand, high intakes of the mix seem beneficial in some cases In Texas, beef cows fed limited amounts of cottonseed hulls and Johnson grain hay in drylot consumed over 5 5 kg of mix per day without ill effects (Riggs, 1958) The supplement consisted of molasses, urea to equal 30% crude protein, phosphoric acid to provide 0 75% phosphorus with vitamin A, and trace minerals

Urea-molasses mixtures sprayed over roughages, such as dry straw, will increase the intake of the straw by cattle or sheep, but the digestibility of dry matter or crude fiber is not improved. Thus, a small supplement of urea may improve the intake of poor quality roughage and thereby supply more digestible energy to the animal. The supplement may also improve the nitrogen status to the point that rate of weight loss may be reduced. But urea-water or urea-molasses mixtures fed with straw or other low quality roughages will not provide the energy needed for growing or lactating animals. Urea can be employed profitably with these roughages only for maintenance rations.

The sudden introduction of urea into a ration has often resulted in lowered feed intake, decline in performance, or both; hence, it is best to introduce the urea by gradual increases over a 2-week period or longer. Once the animals have adapted to rations with urea, they should remain on the diet; otherwise, serious fluctuations in feed intake may result. The adaptation to urea seems to be lost quickly when no urea is fed. Efficient use of urea is favored by feeding regimes that provide small amounts of urea to the rumen microflora throughout the day, in contrast to once- or twice-a-day feeding schedules.

Due to the soluble nature of urea and the rapid release of ammonia, high intakes of urea in a short time can cause illness and even death from the toxic effects of the ammonia. Most cases of urea poisoning result from improper feed mixing or improper feeding. The first symptoms of toxicity become apparent 20 to 30 minutes after consumption, when the animals initially show signs of uneasiness, increased salivation, and slight incoordination. These symptoms may progress to severe incoordination, heavy breathing, failure to stand, tetany, and death. Death may occur from 1 to 3 hours after the initial symptoms. A 5% solution of acetic acid is an effective antidote if given orally before tetany occurs.

It must be borne in mind that urea provides no energy to the ruminant, which means a continuous supply of available energy is needed for maximum utilization of urea. Some form of starch is considered best for this because molasses is fermented very rapidly in the rumen and is not available for very long. Cellulose and feeds with high fiber content do not provide energy fast enough for best use of urea. Feeds with a high carbohydrate content (Table 7.1) are the most satisfactory components of urea containing rations. If the ration contains adequate protein for the animals' needs, there will be no advantage to adding urea, as it will only be lost through the urine.

Studies have shown that urea has no practical value in swine or poultry rations. There is evidence that lambs do not utilize urea as

efficiently as older sheep and cattle. And in general, sheep do not appear to respond to urea supplementation of low quality dry roughage or silage as effectively as cattle. Since calves are essentially nonruminants in the early weeks of life, feeding supplements containing urea should be delayed until after the animals have reached 6–8 weeks of age. Afterwards, the concentrate mixture may contain 1.5–2.0% urea. Depending upon the type of feeds provided, lactating cows can use up to 3% urea in the concentrate mixture satisfactorily. The same holds true for beef cattle on fattening rations. When dry cows, ewes and other mature groups of these species are being maintained at a constant weight, urea may make up as much as 1% of the total ration. Again, the type of ration and the system of feeding are important considerations in the effectiveness of the urea supplementation.

It is important to fortify urea containing mixtures with minerals, especially calcium and phosphorus. This is most critical where the urea mixture replaces cereal grains or oil seed meals, which serve as sources of these and other minerals.

In summary, the current status of knowledge about urea feeding shows that it is not the complete answer for alleviating the protein deficiencies that occur with ruminants grazing native tropical forages. But clearly it can be very beneficial, particularly in making more effective use of some of the by-product feed resources described. Biuret, a much less investigated product, does not appear to be toxic, and it has a slower release rate of ammonia, which could make it more useful than urea in conjunction with grazing. In any case, the wide interest in reducing the dependence of livestock on protein from sources that must also be used to meet human needs means that research on non protein nitrogen resources for livestock feeding will continue. New products are already being developed to overcome the palatability problem of urea, to slow the release of ammonia in the rumen, and to increase the amount of NPN that can be utilized by ruminants.

TREATMENT OF MATERIALS TO ENHANCE FEEDING VALUE

Grinding

The form in which the feed is presented to the animal is important in determining its digestibility and efficiency of utilization. Grinding and pelleting of roughages often increase intakes. Grinding may en-

hance palatability and increase the absorptive capacity per unit of weight. For example, animals will consume more molasses with bagasse or corn cobs if these materials are ground. Grinding of some materials will uncover the cellulose originally protected by lignin or change the pattern of cellulose from crystalline to amorphous type, thus rendering it more susceptible to the action of the microbial cellulases. Grinding and pelleting of roughages in mixtures with concentrates often result in better performance and in the production of a narrower acetate to propionate ratio. The higher propionic acid gives better efficiency of energy utilization since it is a glycogenic (carbohydrate-storage) compound. Pelleting appears beneficial mainly when the ration contains a high percentage of roughage. Some research has also indicated an increase in nitrogen retention as a result of pelleting.

Grinding will increase the rate of passage through the digestive system thus lowering the digestibility of roughages and consequently their value in total digestible nutrients. On the other hand, grinding may lower the heat increment per unit of intake. This would partially compensate for the lower TDN. Therefore, the net energy value of ground roughages may not be greatly different from that of non-ground materials. The main advantage of grinding is to increase total intake of the roughages. Grinding forages with high cell-wall content (grasses) results in greater improvement in consumption than it does in the case of forages with low cell-well content (legumes) because there is more to be gained from the reduction in volume of the feed.

Meyers *et al.* (1965) have reviewed the research on the effects of grinding and pelleting or roughages on the rate of passage of the digesta through the alimentary tract, digestibility, volatile fatty acid production, and animal gains. The review deals principally with temperate zone roughages as there has not been much research done on grinding and pelleting of tropical roughages.

Heating

Experiments indicate that heating or cooking cereal grains may change the propionate–acetate ratio enough to improve the efficiency of energy utilization. The commercial mixture of gelatinized starch and urea (Starea) is another example of how heating can be employed to improve the utility of materials. Cooking may sometimes have the net effect of reducing the biological value of the material by loss of vitamins. But it is often essential for the reduction of toxicity, as with cassava, or the control of diseases, as with garbage collected from urban centers and slaughterhouses, such as bone meal.

Chemical Treatment

Numerous delignifying agents have been tried to improve the nutritive value of roughages Numerous tests made in India, Europe, and the USSR have shown varying degrees of success in the use of alkali compounds, such as NaOH, to improve the feeding value of coarse roughages The sodium hydroxide treatment will make the carbohydrates more soluble and thereby improve feeding value The total digestible nutrient percentage of straw may be increased 15–30% through such treatment Consumption also doubles or triples which constitutes a significant net effect There is evidence that the feeding qualities of bagasse can be improved by chemical treatment Tests in Puerto Rico comparing bagasse rations treated with NaOH to untreated bagasse rations (the rations consisted of 40% bagasse, 27% molasses, 18% corn, 10% fish meal, and 2 7% urea, plus minerals and vitamins) showed a marked advantage for the treated bagasse ration Lactating Holsteins were fed one of the two rations free choice The average daily intakes were 22 5 kg for the treated and 17 1 kg for the untreated The higher intake was reflected in a higher milk yield per day in the first 90 days—22 5 kg vs 17 1 kg, or about 30% in favor of the treated Total lactation yields favored the treated bagasse ration by 15% These results show NaOH treatment improved acceptability by the cattle, as expressed by intake plus improving digestibility

The disadvantage of such treatment is that it requires a good deal of washing and drying, which causes some loss of soluble constituents and necessitates greater inputs of labor The extra labor requirements might not be a serious limitation in certain areas, but the cost of the alkali, the large volume of water required to neutralize the alkali, and the tanks required for holding the material might make this treatment unfeasible The cost of treatment in Puerto Rico, however, was reasonable—$8 00 per ton There was about 30% loss of material in the treatment process, bringing the total cost per ton of material available for feeding to approximately $13 00 per ton The treatment plant was in a dry area so the material could be air dried after treatment To do this mechanically would have nearly doubled the cost of treatment and made the feasibility of feeding questionable

Calcium hydroxide has also been used as a delignifying agent for straws and corn cobs The feeding value is about the same as with NaOH treatment but there are advantages because the residual calcium is less objectionable than the sodium The calcium hydroxide process is normally the more expensive of the two

Rice hulls treated with ammonium hydroxide under pressure

gave better gains for sheep than untreated hulls at a level of 10 and 20% of the ration. Such treatment was intended for the hulls to be used with a nonprotein nitrogen supplement. This product is used in the southwestern U.S.

There is some evidence that specific lignin decomposing bacteria from the soil may serve to decompose lignin microbiologically and thereby improve feeding value. Researchers in Japan have recommended the use of a preparation of bacilli, yeast, molds, and enzymes for the fermentation of roughage to make it more useful in poultry and livestock feeding. For a time a product of this nature was used extensively in the Philippines with rice by-products for swine and poultry feeding, but the practice has been largely discontinued due to inconsistent results.

Although none of the processes indicated for changing the form of feeds have been employed widely in the warm climates, more consideration of these processes seems definitely warranted.

FEED ADDITIVES

Antiobiotics, hormones, and other drugs and chemicals, as well as numerous fermentation products, are being marketed for use with farm animals. Most of these products are claimed to stimulate growth or in some fashion improve the health and performance of animals. Their use is especially widespread in the U.S., Japan, and other temperate zone countries. With the introduction of temperate zone technology and breeds of animals, the practice of using antibiotics and drugs has been accepted in tropical areas in conjunction with swine and poultry production. Many feed and pharmaceutical manufacturers are attempting to expand the sale of various feed additives in the tropics. Even though many of these materials are not deemed dietary essentials, they may prove of value in some situations.

Antibiotics

Since antibiotics are drugs and not nutrients, their influence on animal nutrition is secondary. The mode of action of antibiotics is not clear although several theories have been proposed. There is evidence both pro and con that antibiotics conserve protein, amino acids, and vitamins. Several experiments have shown that chicks and pigs gained as well on 1 to 3% less protein, but the suggested increase in nitrogen retention has not been borne out in balance studies.

It has been proposed that antibiotics may function through selective action on the microorganisms of the intestines—either by favoring the synthesis of nutrients or by controlling transmissible agents either pathogenic or nonpathogenetic which accumulate in houses or lots where animals have been kept for a long time or by favoring the synthesis of nutrients This view is supported by experiments in which calves and other animals treated with antibiotics showed increased growth rates in quarters where animals have been kept for a long time, but not in clean quarters Other studies have shown that conventionally reared chicks and pigs respond to antibiotics, but germ free ones do not although they gain as rapidly

Animals receiving antibiotics have shown faster growth rates and attained a given weight on less feed, possibly because a greater proportion of the total feed was available for growth Often it has also been observed that antibiotic fed animals consume more feed This can not be fully accepted because antibiotic fed animals limited to the same feed intake as controls have often failed to make faster gains Nutritional experiments as balance studies have not demonstrated that antibiotics uniformly improve digestion, absorption, or retention of nutrients by animals In the main, it seems that antibiotics are of most value in alleviating health problems, which influence feed efficiency

Research shows that certain antibiotics added to good rations as well as those inadequate in total energy improve many times the early growth rates of chicks, turkey poults, pigs, lambs, and calves The degree of stimulus is associated with the type of antibiotic, level of feeding, and sanitation conditions For instance, chlortetracycline and oxytetracycline will increase the growth rate of calves and lambs, but penicillin has not proven effective Certain forms of bacitracin, streptomycin, and other antibiotics have given less consistent growth stimuli, or none at all (Maynard and Loosli, 1969)

Studies have shown that pigs respond to supplements of chlortetracycline and oxytetracycline, as well as oleandomycin, tylosin, spiramycin and virginiamycin—at least during early weeks of life Such supplements increase their total daily feed consumption, making less feed required for a unit of gain from weaning to market weight due to fewer number of days on feed Generally, 4% faster gain on about 3% less feed per unit of gain is expected Hence, antibiotic feeding may reduce the feed needed for a unit of gain, decrease the time to get swine to the desired weight, and lower the losses from morbidity and mortality This is enough to favor the use of antibiotics when feeding is for maximum rate of gain In some experiments anti-

biotic feeding resulted in increased dressing percentages and greater thickness of back fat of swine, but because of greater fat percentage in the body, the carcass grade was lowered.

The quantity of antibiotics generally incorporated into rations for pigs and chicks is from 5 to 10 g per ton of feed, while milk replacers and concentrate mixtures for calves contain 20 to 30 g per ton. Chlortetracycline and oxytetracycline have proven best for chicks, pigs and calves. And penicillin and streptomycin are used to reduce scours in calves, although penicillin may have a depressing influence on rate of gain. Zinc bacitracin has also come into use in calf-starter rations.

Results differ on the effects of antibiotic feeding for beef cattle. Although favorable growth response has been obtained when chlortetracycline was fed to suckling calves; there is a problem of assuring uniform intake. In feedlot operations, antibiotic feeding may help prevent foot rot, some respiratory infections, and liver abscesses, or reduce the morbidity when these diseases occur in fattening steers or heifers. Antibiotics have not been found in the meat of animals fed at growth stimulating levels, but at high levels of feeding residues can be detected in the meat. Regulations usually require that antibiotics be withdrawn from the diet several days before slaughter. In any case, there is little or no risk to the user of the meat since antibiotics in common use are destroyed by cooking.

Feeding antibiotics to lactating dairy cows does not seem to directly influence milk yield, although field trials in commercial herds have shown improved performance resulting from better health, especially, reductions in frequency of foot rot, respiratory infections, and other disturbances. Low-level feeding (22 mg per 100 kg of body weight per day) is not an effective cure for foot rot, mastitis, or other specific infections, but this level does appear to reduce the incidence and severity of these infections in dairy herds. At this level of intake antibiotics will not appear in the milk, but if the intake is 110 mg or more per 100 kg, the milk may contain appreciable amounts of antibiotics.

Antibiotic feeding of lambs has given variable results. Even in drylot feeding its use is not as widespread as with cattle. Experiments in Texas showed that feeding 100 mg of chlortetracycline by capsule to lambs caused feed refusal and weight loss. Tests with penicillin and streptomycin gave similar results. On the other hand, daily intakes of 5–20 mg of these drugs did not reduce appetite, and intakes of 20 mg of chlortetracycline per kg of feed resulted in slightly faster gains. Results of experiments with lambs are about equally divided between some improvement in gain and no change. The use of anti-

biotics as implants has not proven effective in reducing mortality of newborn lambs The current consensus is that there is as yet no clearly established place for antibiotic feeding with sheep

Age of the animal is an important factor in determining the effects of antibiotic feeding Young animals show the most pronounced influence With the recommended levels of feeding there is no serious carryover effect after withdrawal In fact, there is a decline in growth rate immediately after withdrawal If the young animals are removed from quarters with a concrete floor to pasture or dirt lots in areas where internal parasites prevail, the decline in performance may be more dramatic A series of trials conducted in Colombia showed that dairy calves reared on concrete and fed starter with antibiotics had much poorer gains from 6 to 12 months of age after going on pasture than calves reared from birth to 6 months in small, individual pens on a grass sod without antibiotic feeding before going on pasture

While antibiotic feeding may reduce the frequency and duration of health problems, the recommended levels of feeding will not entirely prevent health problems In other words, antibiotic feeding may help, especially when the animal is exposed to pathogenic organisms, but it cannot be expected to replace sanitary practices and proper nutrition and management The value that antibiotics may have in assisting animals to withstand the stress of the physical environment in warm climates has not been discerned This area needs further research

Feeding large amounts of antibiotics to cattle over a year of age, or sheep beyond 6 months of age, that have not been previously accustomed to receiving this type of feed, may result in serious temporary reductions in feed intake, diarrhea, and lower digestibility of the feed

Hormones

Certain hormones have proved effective as growth stimulators It is common practice in the U S and some other countries to use estrogens and synthetic compounds with estrogenic activity, such as stilbestrol (diethylstilbestrol), either in the feed or as implants during the fattening period for cattle and lambs The recommended amounts—3–9 mg for sheep and 24–36 mg for cattle, given in one or more doses—have produced significant improvements in rate of gain and feed efficiency The increases in rate of gain reported range from 5 to 28%, depending on the ration, sex, and breeds involved Although the use of stilbestrol and other hormones in conjunction with grazing is much

less common than use with drylot feeding, experiments in southeast Georgia (McCormick *et al.*, 1961) and Colombia (ICA, 1968) have shown that some hormones may also be effective for cattle on pasture. In Georgia, steers implanted with 15 mg of stilbestrol gained 25% more rapidly than controls on pasture plus limited concentrates. In Colombia, steers implanted with 36 mg stilbestrol, grazing at the level of one animal per hectare for 196 days, gained at the rate of 0.6 kg per day, which was 22% faster than the rate for nonimplanted controls. Other trials in Colombia indicate 200 mg progesterone plus 20 mg of estradiol may stimulate gains as much or more than those from stilbestrol.

A number of countries have restrictions on the use of stilbestrol. Equally significant in discouraging the use of this hormone in many tropical areas is the discrimination in the markets against animals carrying appreciable amounts of fat. Even so, the use of stilbestrol will probably increase in some areas with the development of improved pastures for finishing cattle or lambs to market weight. Experiments are underway in Puerto Rico to determine the value of stilbestrol for steers and bulls grazing highly fertilized grass pastures.

As pointed out in Chapter 4, high ambient temperatures tend to reduce thyroxine secretion rate. Theoretically, the use of thyroid-active materials to stimulate growth of body tissue and wool as well as secretion of milk by creating a mild hyperthyroidal state is attractive. Until now this hypothesis has received very little attention except in a few studies in temperature controlled laboratories. Current results indicate that attempts to restore or maintain high levels of thyroxine by supplementary feeding of iodinated casein may worsen rather than improve animal performance.

In the temperate zones, thyroprotein feeding has increased the growth rate of young pigs and calves under some conditions. The results with calves have been variable. Feeding thyroprotein to lactating cows has increased milk yields and fat percentage at least during short experimental periods. Experiments in New York State showed that cows fed iodinated casein from 50 days after calving through the day of "drying off" did not have total lactation yields higher than controls. The maximum increase in yield was 8.8%. After the twenty-second week yields of the treated groups dropped below those of their control pairmates. There are also indications of carryover effects from thyroprotein feeding, such as reduced breeding efficiency which make its feasibility questionable. It may be employed satisfactorily for short periods of time to increase milk yield of an entire herd but while it is being fed, more feed must be provided. Attempts to increase the weaning weight of beef calves, lambs, and pigs have met

with variable success Difficulty in obtaining uniform rate of intake by suckling animals is a real problem

In general, the cost of the source of thyroxine, the cost of extra feed to make thyroprotein feeding successful, and the difficulty of getting uniform intakes, particularly where the main source of feed is pasture, make the use of thyroprotein of questionable value in most tropical areas It could be, however, that for some enterprises near urban centers the practice would be warranted

Thiouracil and other goitrogens, which interfere with the rate of secretion of thyroxine by the thyroid gland, have been tested with livestock These compounds depress growth but increase rate of fattening Diethylstilbestrol in combination with thiouracil will improve finish and market quality without depressing growth rate in poultry, but goitrogens appear to be of little value in finishing lambs and pigs Similarly, the results with fattening cattle have not been considered very successful Hence, thyroid regulating compounds are currently of little practical importance Inasmuch as the physical environment of much of the warm climate areas tends to suppress thyroid activity, these compounds are likely to be of less value there than in the temperate zones

Other Feed Additives

Arsenic compounds are often used to prevent certain diseases, such as coccidiosis in poultry Like antibiotics, they may also stimulate growth of chicks and pigs, especially under unfavorable conditions—that is, when the chicks or pigs are unthrifty or exposed consistently to disease organisms Arsanilic acid and 3-nitro-4-hydroxy-phenylarsenic acid have been employed most widely for swine and poultry at levels of 0 002 to 0 009% of the total diet But since arsenic compounds are highly toxic, mixing them into the feed must be done carefully Healthy animals maintained under good sanitation practices exhibit little benefit from arsenic materials Dairy calves have shown no responses to arsenic compounds

Numerous other materials, such as enzymes and rumen cultures, have been tested as feed additives, but their use has not become widespread in practical feeding due to inconsistent experimental results, cost, and lack of availability of standardized products Since feed additives are largely a product of temperate zone evaluation, they should be appropriately tested before application to environmental conditions of the warm climates

TABLE 7.2
Rations, with percentages of various ingredients, used successfully for feeding livestock and poultry in tropical areas

Ingredients	Swine				Poultry				
					Chicks & broilers			Layer & breeders	
	1	2	3	4	1	2	3	1	2
Corn, ground					36	30	20	35	30
Cassava meal	69	55	36						
Bananas, mature				70					
Citrus pulp									
Gram (Mung bean)								6	
Molasses		10			4				
Pineapple bran									
Rice bran			26			10		18	10
Rice screenings					20		12		
Sorghum, ground						25	20		26
Wheat bran						7	10		10
Corn gluten feed					4			12	
Corn bran								10	
Alfalfa meal			5			4			4
Copra meal			22						
Cottonseed meal	7	7		6			20		3
Fish meal		3	8		8	4	5	4	3
Groundnut cake						8	5		3
Meat & bone meal					4	4		7	3
Sesame meal							4		
Soybean meal	20	21		20	20	6		4	4
Protein supplement (24%)									
Urea									
Ipil-ipil seed meal					2			2	
Ground bagasse									
Cane tops									
Gram husks									
Green maize									
Green chopped napier									
Pineapple silage									
Bone meal	2	2		2					
Mineral & vit suppl	2	2	3	2	2	2	4	2	4

TABLE 7 2 (con't)

Dairy Cows										
Conc suppl			*Comp ration*			*Dairy calves (3 mo +)*	*Fattening cattle*		*Work oxen*	*Ingredients*
1	*2*	*3*	*4*	*5*	*6*		*1*	*2*		
30	55	40	37			10				Corn, ground
						20				Cassava meal
										Bananas, mature
							35			Citrus pulp
30		40								Gram (Mung bean)
			25	6	6	7	10	49	2	Molasses
				14	12					Pineapple bran
10						30			5	Rice bran
						8				Rice screenings
										Sorghum, ground
	20									Wheat bran
										Corn gluten feed
										Corn bran
										Alfalfa meal
					6				5	Copra meal
20	25					10	17			Cottonseed meal
										Fish meal
10		15	9			10				Groundnut cake
										Meat & bone meal
										Sesame meal
				4						Soybean meal
								12		Protein supplement (24%
			2	1	2	3	2	3		Urea
										Ipil ipil seed meal
			25				35			Ground bagasse
									88	Cane tops
		5								Gram husks
								38		Green maize
				75						Green chopped napier
					74					Pineapple silage
										Bone meal
			2			2	1	1		Mineral & vit. suppl

dian breeds of cattle that had been developed from nutrition experiments conducted in India. The estimated requirements were somewhat lower than those from the temperate zone. But in the more recent edition (Sen 1964) the recommendations for cattle in India represent an average of the low and high values from Morrison's standards. Therefore, temperate zone technology is currently the guide for feeding domestic livestock throughout the world. The allowances in these standards are, in general, set higher than average requirements to provide a margin of safety, since most practical feeding programs are intended to provide for groups of animals that may at a given time include individuals of different ages, stages of pregnancy, or levels of milk production. In Chapter 4 it was pointed out that when the ambient temperature exceeds 27°C there could be a significant increase in the animal's requirements for body maintenance. The margin of safety in the allowances of NRC and Morrison may not be sufficient for the increased energy needs for maintenance, but clarification must await further research.

At present the livestock producer in the tropical areas must, of necessity, approach evaluation of his feeding program empirically due to the possible inappropriateness of the accepted standards for his herd or flock. Another serious limitation is the paucity of information on assessment of the feedstuffs available locally. The digestion coefficient of the local forages may fluctuate 20% or more, depending on stage of maturity or extent of dry period. As indicated above, the nutritive value of a by-product, such as rice bran, may likewise vary 20%, depending on method of processing. The lack of standard guidelines for livestock feeding is a particularly serious problem in the warm climates, where the limited feed resources should be utilized with maximum efficiency. Portions of Chapter 14 deal further with management of feed resources.

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IV

LIVESTOCK BREEDING

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8

Characteristics of Breeding Stocks

In discussions about the development of viable livestock enterprises in the warm climates one often hears radically opposed views: "Much of the needed change could be brought about by improved breeding," versus "There is no point in attempting any genetic improvement in this region." The latter case could better be stated: "Until management can be changed, by means of such improvements as quality feeds, more uniform feed supplies, and some measures of disease and parasite control, there is no point in planning for genetic improvement." Our current knowledge supports this position but we ought not to accept it as final, for if we did, our inaction in this sphere would shut out any possibility of genetic improvement. A more profitable approach would probably be to include breeding as part of the overall program of livestock improvement. Selective breeding is a slow process; consequently, as plans are projected for developing livestock production, they should include consideration of stock with greater genetic potential than the current stock. This is especially true if selective breeding is contemplated from within existing stocks because the decisions made on identification of those animals which will contribute most to subsequent generations can not be measured for a number of years. In the meantime, there is an opportunity to

improve husbandry conditions. In short, decisions about breeding should be made with respect to the anticipated future of husbandry in an area.

This chapter and the two following chapters provide a brief survey of some of the characteristics of the stocks presently being used and certain systems of breeding that may be employed for increasing their genetic potential. (Some groups are referred to as types which means they are distinguishable by some phenotypic characters, while others are identified as breeds, meaning rather specific standards of phenotypic traits have been described).

There are many types of domestic livestock and poultry existing in the N-S 30° latitudes. Among them are (1) groups indigenous to the areas—that is having existed in the area, as far as we know, nearly since domestication or at least for several hundred years; (2) admixtures among local types and groups introduced from elsewhere; and (3) groups recently introduced from other areas, principally western Europe and North America.

Most indigenous types are the result of "natural selection" produced by the pressures of the environment and some selective breeding on the part of man. Even the illiterate farmer or nomadic tribesman, with no knowledge of the formal principles of genetics and animal breeding, has usually been aware of the relative merits of his animals and the concept that like begets like, and has consequently exerted some selection pressure in favor of animals superior in pulling power, milk yield, or meat production or even color pattern. Uniformity within groups occurred with geographic isolation. Or sometimes a large land holder, community leader, or governmental agency became interested in a type and by example, as well as by providing breeding stock, influenced the type of certain groups of animals.

Apart from man's efforts to direct breeding, natural selection has played a role in the establishment of types that could survive the rigors of extreme environments, such as the camel of the desert and the yak of the Himalayan highlands.

It is far beyond the scope of this book to describe, or even list, the identified groups of livestock in the N-S 30° latitudes. The world dictionary prepared by Mason (1969), as well as reports by Epstein (1969), FAO, Joshi and Phillips, (1953), and Joshi *et al.*, (1957) and other publications, should be consulted to get a more complete picture of the species and breeds of livestock in various countries.

CATTLE

There are dozens of more or less distinct breeds of cattle, all stemming originally from two species. non-humped (*Bos taurus*), and humped

(*Bos indicus*). *Bos taurus*, usually synonymous with "European type" cattle, has been developed largely outside the N-S 30° latitudes. *Bos indicus*, referring to "Zebu type" cattle originating in southeast Asia, especially India, characterizes the most widely distributed groups within the tropics. Crosses between the two types are fertile, and the last century has seen a vast mixing of these species. The pure European types predominate in Europe, northern Asia, North America, a portion of north Africa, and Australia. The Zebu types predominate in southeast Asia, central Africa, including the island of Madagascar, and Latin America. Cattle of an intermediate type—those with phenotypic characteristics indicating early crossing between *Bos taurus* and *Bos indicus*—are numerous in both the northern and southern portions of Africa, the southern part of central Asia and Asia east of the Himalayas.

The European breeds that have been used most widely in the N-S 30° areas are the Holstein and Jersey, as dairy breeds, and the Shorthorns and Herefords, as beef breeds; however, the Charolais is rapidly increasing in popularity. It is difficult to discern which breeds of the Zebu type have had the greatest impact outside their native habitat. The breeds most widely used for milk in experimental programs of various countries have been the Red Sindhi, Sahiwal, and Gir from India and Pakistan. Those most used for beef production include the Kankrej, Ongole, and Gir, also from India and Pakistan. Of the intermediate types, the Boran of central Africa seems to have proven most popular outside its home territory.

With the exception of India and Pakistan, the current cattle populations of nearly all countries consist of an "indigenous type"; an intermediate type, resulting from crossing between the indigenous breed and other breeds, either *Bos taurus* or *Bos indicus*; and "high grades" of either *Bos taurus* or *Bos indicus*. For example, in Taiwan there are three native breeds of the Zebu type which were brought to the island from South China in the days of Chinese colonization. These have been replaced almost completely by crosses with breeds from India for draft and beef. Various gradations of Holstein breeding predominate for commercial dairying. A similar situation has occurred in the Caribbean islands and Latin America where the Criollo, or native-type cattle, have now been largely replaced by gradations of Zebu for beef and Holstein and Brown Swiss for dairy purposes.

In Burma, Thailand, Cambodia, Indonesia, the Philippines, and other countries in the immediate vicinity, including New Guinea and northern Australia, are found the most "primitive" type cattle in the world today—the Bateng (*Bos sondaicus*). These cattle are small in comparison to other cattle; and the ones that have remained in isolated areas longest have many of the phenotypic characteristics of

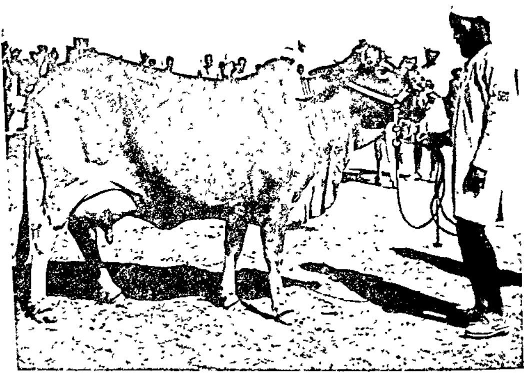

FIGURE 8.1
The Sahiwal is considered the best dairy breed among *Bos indicus*, with selected cows producing over 5000 kg of milk in a lactation They are rather short-legged and heavy boned as compared to most other *Bos indicus* breeds. (Courtesy H. C. Pant).

deer—short tail, sloping rump, small bones, and branching horns. In other locations the pure Bateng has been replaced by crossing with Zebu or European breeds.

India and Pakistan remain the largest reservoir of "pure Zebu" types. Joshi and Phillips (1953) classified the cattle of the Indian subcontinent into 6 main groups according to area of origin and phenotypic characteristics, such as color, shape of head, and horns. They described 28 recognized breeds distributed among these groups. For this same area Mason (1951) classified the cattle, mainly on the basis of utility, into 7 major groupings and 37 breeds. The terminology employed by Mason is descriptive and indicative of the emphasis placed on selection for certain characteristics. The groups, with an example of a breed in each, are as follows: (1) large dairy type, e.g., Sahiwal (Figure 8.1); (2) lyre-horned or heavy draft, e.g., Kankrej;

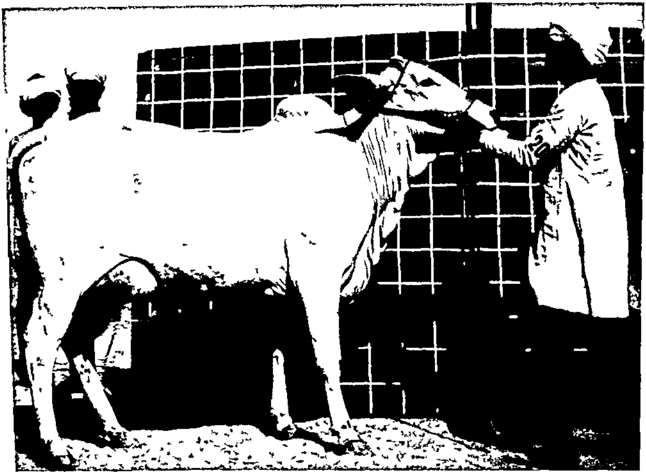

FIGURE 8.2
The Hariana is one of the most widely distributed breeds in India. It is considered dual purpose – draft and milk. The bullocks are popular for field work. They are grey-white in color with horns shorter than those of most Indian breeds. (Courtesy H. C. Pant)

(3) grey-white shorthorned or medium draft, e.g., Hariana (Figure 8.2), (4) Dhanni or black and white medium draft, e.g., Dhanni, (5) Mysore (South India) or rapid draft, e.g., Hallikar (Figure 8.3), (6) Gir (west India) type or milk and slow draft, e.g., Gir, and (7) hill type or small cattle, e.g., Purnea and Deshi (see Figure 1.5).

Mature body weights of females for the breeds listed are 386, 422, 356, 345, 375, 385, and 182 kg, respectively. Mature males are usually 20–30% heavier. The characteristic milk yields are highly variable, with average lactation yields of about 250 kg for the Purnea and Hallikar breeds up to over 1800 kg for the Sahiwal breed. Certain herds of Sahiwals have achieved an average yield of 2300 kg, and individual cows have produced more than 5000 kg in a single lactation. The average age at first calving is 42–51 months on improved farms and up to 54 months among village cattle. Although there is some indication that certain breeds calve later than others – e.g., 51 months for Sahiwal

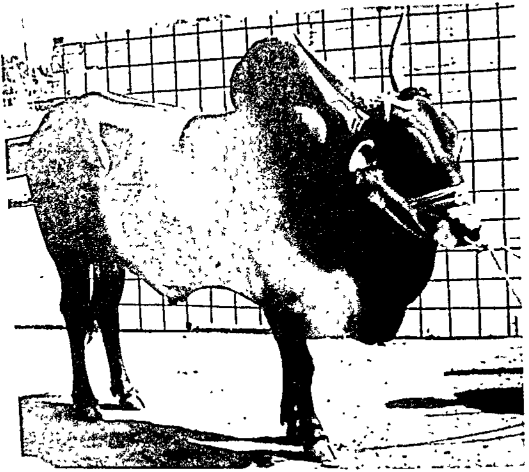

FIGURE 8.3
A bull of the Hallikar breed, found chiefly in southern India (Mysore State). A long head and erect horns are characteristic of the breed These animals are useful for rapid draft, but the cows are poor milkers (Courtesy H C Pant)

and Hariana versus 42 months for the Red Sindhi and Bhagnari breeds —the high intra herd variability for this trait suggests this may be influenced by environmental conditions rather than by heredity. The mean lactation length varies among breeds, but seems closely related to total yield. Sahiwals, for example, have a mean lactation length of around 300 days, as compared to 167 days for Hallikar. The calving interval is well over a year in all Indian breeds (range 410 to 580 days) and mortality for females between birth and one year of age ranges from 15–50%, depending on the general herd environment and the frequency of serious disease outbreaks. Some herds have lost up to 60% of their calves under one year of age in a single year (Ngere, 1970).

The Indian Zebu, whether kept as a family cow or in one of the Indian milk colonies, is for the most part milked with the calf present, therefore, the milk yields reported infrequently include the milk consumed by the calf Shortened lactations and lower than average yields following the death of the calf, especially in the early part of lactation, have made milking with the calf present the accepted practice in India and Pakistan On the other hand, the Sahiwal herd at Pousa, India has been milked a number of years without the calves present The mean gestation length for Zebus is from 283 to 291 days, which is somewhat longer than for the majority of European breeds

The Indian Zebu males begin fertile services at 2½ to 3½ years depending on breed and level of feeding The bullocks are also put to work in this same age range

For Africa, Joshi *et al* (1957) describe 8 groups of indigenous types according to location and phenotypic characteristics—mainly presence or absence of humps, position of hump (thoracic or cervical), size of horns, and color markings Using location and these traits, they subdivided the groups into 33 major breeds The 8 larger groups are described as follows (1) The humpless cattle of the lower Nile Valley include the Damietta of Egypt and Syria (2) The Zebus of the sub Sahara have many characteristics similar to those of groups native to the India subcontinent (3) The N'Dama of West Africa is representative of the humpless, straight-backed cattle (Figure 8 4) (4) The Kuri type cattle of the Lake Chad region are characterized as humpless but with bulbous horns (5) The Nguni (Figure 8 5) of Uganda represents cattle that are medium in size with large or medium sized, lyre-shaped horns, small humps, and moderately sloping rumps (6) The types of East Africa are a conglomerate of groups, but in general they appear to be predominately derived from Zebu stocks of India The Boran is one of the most widely dispersed breeds of this group (7) The Sanga (Figure 8 6) and lateral-horned Zebu are native to southern Africa The Africander is the most popular of the lateral horned breeds (Figure 8 7) These cattle are medium to large in size as compared to other breeds in Africa (8) The Madagascar Zebu has been grouped separately due to the isolation of its habitat, nevertheless, it is similar in many respects to the Indian Zebu and other Zebu types of Africa

As with the Indian and Pakistani Zebu, there is a wide range in the characteristic mature body weights of females of African breeds —e g , 240 kg for N'Dama in contrast to 540 kg for Africander females In general, the average lactation milk yield for the African breeds is less than for those identified as "milk breeds" in India, although herds with an average yield per lactation of over 1500 kg have been

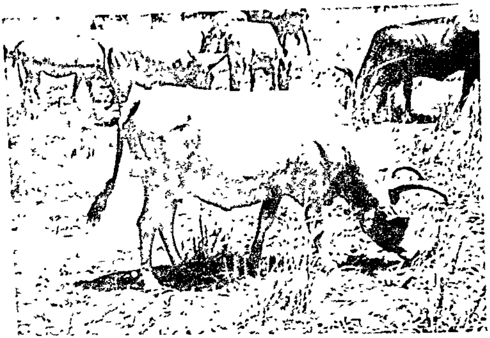

FIGURE 8.4
The N'Dama is a small humpless type, usually fawn, light red, or dun colored, with lyre-shaped horns. It is among the smallest breeds of central Africa and a poor milk producer. (Courtesy J. K. Loosli, Cornell University).

reported. The length of gestation, age at first calving, length of calving interval, and percent mortality from birth to one year are about the same as for breeds in India; but the length of lactation is only about two-thirds that for India. It is also common practice in most of central Africa to milk the cows with calf present.

The Criollo type cattle of Latin America were introduced by the Spanish and Portuguese during colonization from their home countries or sections of North Africa. These cattle are of the *Bos taurus*, or humpless, type. Pinzon *et al.*, 1959 describe four breeds found in Colombia that are direct descendents of the early introductions or originated from crossing with a breed from northern Europe, such as the Romosinuano which developed from a Red Poll-native cross. DeAlba and Carrera (1958) describe several other groups of the Criollo type found in Nicaragua, Venezuela, and Peru. Criollo breeds, except for the Blanco Orejinegro of Colombia (Figure 8.8), are highly variable in color, although medium red to dark brown is predominant. The Criollo tends to be medium in size compared to other groups. The Costeño Con Cuernos of Colombia (Figure 8.9) is about the smallest —around 385 kg for mature females—while the Criollo of the Lake Maracaibo region of Venezuela has a mature weight of around 500 kg. (see Figure 1.12). The groups in Venezuela and Nicaragua have rela-

FIGURE 8 5
Nguni cattle, which are native to southern Africa are medium sized, short-horned, with small humps, and moderately sloping rumps They are maintained largely for milk but are slaughtered on festive occasions. Oxen are used as draft animals. (Courtesy J. C. Bonsma, University of Pretoria)

tively good milk yields—up to 2200 kg per lactation—while those in Colombia and elsewhere are rather poor milkers—500–800 kg per lactation. Except for those in the Lake Maracaibo region, the Criollo have short lactation periods (about 150 days) and need the presence of the calf for milking. The Criollo appear to calve at an earlier age (36–42 months) and have considerably better breeding efficiency, as measured by calving interval (372–420 days) and shorter gestation periods (279–283 days), than the majority of the cattle in central Africa and southeast Asia.

The "Spanish," or Criollo type, cattle have been replaced almost entirely by Indian type Zebus—especially in Brazil where efforts have been made to develop Zebu types for dairying as well as beef production. Currently Brazil has several distinct groups originating from early importations of Indian and Pakistanian breeds. Other groups have been developed from a crossbred foundation of two or more Zebu breeds, such as the Indubrasil. The "Brazilian type"

FIGURE 8 6
Sanga cattle are an unimproved type, native to the dry regions of South West Africa, Botswana, and the Union of South Africa They are very hardy but they grow slowly and milk yields are low (Courtesy of J C Bonsma, University of Pretoria).

Zebu has accounted in part for the shift of the beef producing enterprises in Latin America from the Criollo to the Zebu. However, the American Brahman, a Zebu type stemming from the Indian Zebu, has influenced this shift more significantly in South and Central America north of the 30° S latitude.

The other major tropical area, northern Australia, has no indigenous cattle in the sense that the other areas discussed do. Cattle were first introduced in large numbers into Australia around 1850. These introductions came principally from northern Europe. From a mixed foundation of European breeds came the Illawarra Shorthorn, originating in New South Wales. This breed has contributed to the current

FIGURE 8 7
A young Africander bull representing an improved breed of lateral-horned type developed from the native Hottentot cattle of the Cape of Good Hope This is one of the largest breeds of African cattle and has been used extensively for beef production in the Union of South Africa, both as a pure breed and for crossing (Courtesy J C Bonsma, University of Pretoria)

cattle population in northern Australia In the north, selected groups of Herefords have been developed, and the crossing of Zebu and European types has become popular for beef production.

In many areas of the warm climates cattle are expected to serve the triple purpose of furnishing agricultural power, meat and milk, and hides for leather. As indicated for the groupings of cattle in India and Pakistan, the greatest emphasis in these countries has gone toward draft. In the drier northwestern portion of India and the western portion of Pakistan—the home tract of the Sahiwal, Gir, and Red Sindhi breeds—more attention has been given to milk production, hence, these breeds have emerged as probably the best milk producers of all the types indigenous to the tropical areas, except for some of the Criollo mentioned earlier.

In many African countries cattle have been involved in semi-nomadic herding systems. With the exception of a few breeds, there has not been as much selective breeding toward a single purpose as in India. A large portion of the cattle in Latin America have been

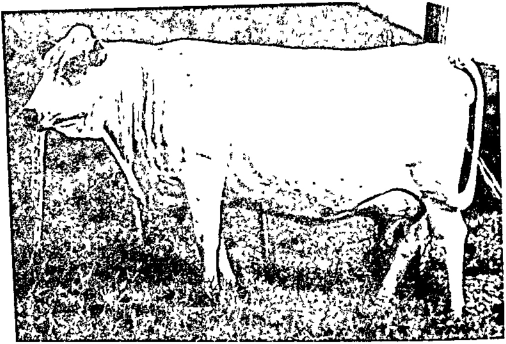

FIGURE 8 8
Blanco Orejinegro cow, Criollo (*Bos taurus*) type, native to north-central Colombia. This breed is white with black points and medium in size. Temperament is considered good. It is reasonably good for meat production, but rather poor for dairying. (Courtesy R. K. Waugh, Rockefeller Foundation).

maintained in a "semi-wild state," that is, running free on large areas of range lands, without fencing or an appreciable amount of management. Once a year or so the cattle are rounded up and some removed for slaughter. Hence, the Criollo have undergone little selection for merit beyond the general pressures imposed by the natural environment. In the small farm holdings of Latin America, cattle have been used to some extent for draft and milk production, but their main purpose has been to contribute fertility to the area of the farm that was idle between rotations of the cropping plots. These practices are undergoing change, but large segments of the cattle population are managed in this fashion even now.

The body weights for mature females and milk yields cited for the indigenous groups represent herds kept at governmental experiment stations, so they are higher than statistics for animals kept in small villages. The estimated average milk yield for cows in rural areas in India is about 200 kg per lactation and that for African cattle less than 150 kg, largely because of poor feed supplies. Over the centuries the indigenous types have been required to fend for themselves, little wonder their performance does not fit the modern day concept of animal production. With the advent of artificial breeding and frozen

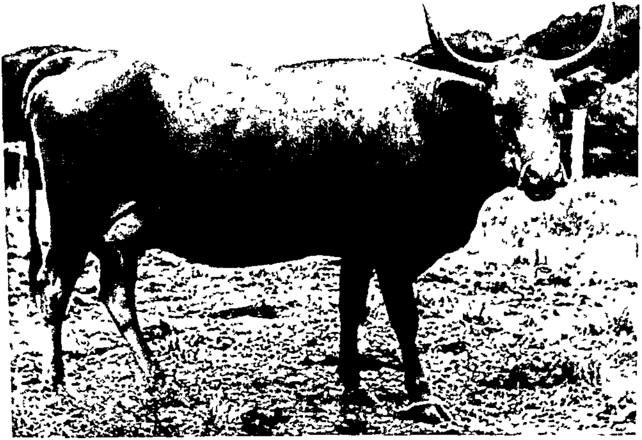

FIGURE 8 9
A second lactation Costeño Con Cuernos cow This breed is a Criollo (*Bos taurus*) type native to the lowland region of northern Colombia It is considered a milk breed (Courtesy R. K Waugh, Rockefeller Foundation)

semen there has been a tendency to change the indigenous cattle in tropical areas by crossing with breeds from outside. In many cases, crossing or grading up (two or more crossing to European types) has been undertaken with little planning and consideration of the general resistance to poor environments acquired by the native types. This aspect will be dealt with further in the following chapters.

SHEEP

Sheep (*Ovis aries*) appear to have been the first species of livestock to be domesticated. Breeds have been developed for specific purposes and to fit into various environments—such as the very small sheep found in the Sahara region of Africa, which may be from 40–60 cm in height at the withers and 20–30 kg in body weight at maturity due to the sparse feed supplies. Approximately 36% of the world's sheep numbers are in the N-S 30° latitudes. Of the more than 500 breeds in the world, about one-third are native to the N-S 30° region (Mason, 1969). Various breeds or groups are distinguishable by their

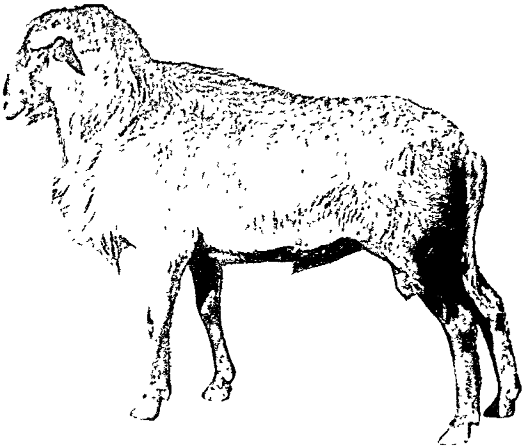

FIGURE 8.10
The West Indian or Barbados Black-belly sheep has a coat consisting almost entirely of hair. The breed is popular in the Caribbean islands for meat and milk production. It is brown with black belly

anatomical characteristics, color, face covering, and type of body covering. In general, the quality of the wool decreases with latitude: sheep with long, medium, and fine wool are found mainly above the 30° N latitude, whereas sheep in the low latitudes have coarse wool and hairy coats such as the Barbados Black-belly (Figure 8.10). Still another system of classification has to do with the shape of the tail. Mason and Maule (1960) describe the three main groups indigenous to eastern and southern Africa as thin-tailed, fat-tailed, and fat-rumped.

The primary reason for keeping sheep varies with culture and environment. The nomadic tribes of north Africa and southern Asia are dependent upon sheep primarily for milk, and consequently prize milking qualities above body covering. In Jordan, for example, over 60% of the country's total milk supply is from sheep and goats. Sheep are often kept principally for fur production (e.g., the Karakul)

as well as for the usual main uses—meat, wool, and skins. Since sheep are such a vital segment of human life in northern Africa and southeastern Asia, Chapter 15 is devoted to a consideration of the present and future status of sheep production in this vast region of the warm climates.

The Australian Merino is the main fine wool type of the tropical areas. Although this group originated on the Iberian Peninsula, it soon became the major type in Australia and then—through exports from Australia or other areas—the Merino is the type currently numbering the greatest part of the sheep population of the world today. Merinos have been introduced into many areas as purebreds or rams have been brought in for crossing. In comparison to the British mutton breeds, the Merino is a slow grower and poor in reproduction. Nevertheless, the Merino has the ability to survive and produce under rigorous environmental conditions of high temperatures and poor feed supplies. The Merino has been imported mainly for improving the quality of wool or reducing the hairy coat condition prevalent in other breeds in the warm climates.

Terrill (1968) attempted to describe the suitability of 84 breeds to various environments. Table 8.1 shows the variations in type of coat, the principal use in their current habitat, and the feed conditions for some breeds native to tropical areas. The climatic conditions, based on general classifications of temperature and humidity, are also for the local habitats. Such classifications are useful as a starting point in locating breeds that could thrive in other areas similar to their own, and also in indicating where breeds might be obtained to improve body covering or possibly enhance meat characteristics without losing hardiness for a tropical or subtropical environment. Before proceeding on more than a sampling trial basis, one would certainly want to know more about the potential of a breed than merely whether it was surviving in a particular area.

The contrasts in average performance traits between the medium to larger sheep breeds in the Middle East and the India subcontinent are not as pronounced as for the indigenous cattle. For single lambs among breeds in north Africa (Ausimi and Awassi) and India (Bikaneri) birth weights range from 2.7 to 3.2 kg; the range at 6 months is 20–25 kg, and at one year of age, 28–34 kg. The average mature weight for females is 40–50 kg. These weights are 50–100% lower than for breeds in most of the temperate zone areas. The mean lambing percentage for the indigenous types is 80–90% per year, with some groups as high as 117%. The average milk yield for the Awassi, representing about 70% of the milking sheep in the Middle East, is around 200 kg in approximately 190 days. However, some

TABLE 8 1
Projected suitability of some breeds of sheep for different climates and feed conditions.

Breed or type	Main area of concentration	Type of coat	Principal use[a]	Apparent suitability to. Feed conditions	Climate Temp.	Climate Humidity
Ausimi	Egypt	Coarse	W,M	Sparse	Hot	Dry
Rahmani	Egypt	Coarse	W,M	Sparse	Hot	Dry
Berber	North Africa	Coarse	M,W	Sparse	Hot	Dry
Beni-Guil	Morocco	Coarse	M,W,	Sparse	Hot	Dry
Somali	Kenya	Hairy	M,S	Sparse	Hot	Dry
Blackhead Persian	South Africa	Hairy	M,S	Sparse	Hot	Dry
Merino	Australia	Fine	W,M	Sparse	Hot	Dry
Polwarth	Australia	Medium	W,M	Medium	Warm	Humid
Bellary	India	Coarse	W,M	Sparse	Hot	Medium
Bhakarwal	India	Coarse	W	Medium	Hot	Medium
Bhadarwash	India	Coarse	W	Medium	Warm	Medium
Bikaneri	India	Coarse	W,M	Sparse	Hot	Dry
Deccani	India	Hairy	M	Sparse	Hot	Dry
Hassan	India	Coarse	W	Medium	Hot	Medium
Karnah	India	Medium	W	Medium	Medium	Medium
Mandya	India	Hairy	M	Medium	Hot	Medium
Nellore	India	Hairy	M	Sparse	Hot	Dry
Rampur Bushahr	India	Medium	W	Medium	Medium	Medium
Lohi	Pakistan	Coarse	W,M,D	Medium	Warm	Medium
West Indian (Barbados Black-belly)	West Indies	Hairy	M,	Medium	Warm	Humid

Source Adapted from Terrill, 1968
[a]D = Dairy, M = Meat, W = Wool

flock averages have exceeded 300 kg, exclusive of that given the lambs (Choueiri, 1969).

In some respects sheep indigenous to the tropical areas have been subjected more to selective breeding for performance than native cattle. This is evident from the greater uniformity of phenotypic characteristics of sheep in most local areas as compared to those of cattle, the wider use of crossing to develop new groups, and the tendency for castration of poor male lambs in the prepuberal stage. Sheep flock owners sell their poor lambs, both male and female, very readily. In contrast, the Indian farmer castrates the most rapid growing male calf for a potential bullock. If the larger male calves reflect the milk producing ability of the cows, this means that little attention is being given to passing this superiority to the next generation through a son.

GOATS

Goats (*Capra hircus*) belong to the same family as sheep—*Boridae*, or hollow-horned ruminants. The varieties are sometimes difficult to distinguish. The world goat population is nearly 380 million, with about 67% of these in the N-S 30° latitudes, principally in Africa and the Far East. Of the 140-odd breeds described by Mason (1969), about 55% are indigenous to the warm climates. The indigenous breeds vary in size from the dwarf types in the coastal regions of Africa and the state of West Bengal, India to the rather large animals kept by Arab tribes in the semi-desert areas. Like sheep, the dwarf types are only 40–50 cm in height and weigh 15–20 kg at maturity, as compared to 70–85 cm height and 50–80 kg weight for the larger types (Devendra and Burns, 1970).

Goats can travel long distances and require less frequent watering opportunities than sheep or cattle. Sheep need better herbage than goats which can exist on browse or many aromatic and other weeds rejected by other ruminants. In most countries goats are relegated largely to two areas—the outskirts of cities, where they subsist on refuse, and the more remote and poor agricultural areas, where they browse on incidental vegetation. In arid areas, where vegetation is sparse and land too steep for cultivation, goats roam more widely than other herbivores and glean their requirements from browse and weeds neglected by other species. They also have a higher tolerance to feed supplies deficient in crude protein, phosphorus, and sodium. Though goats consume a wider range of plants than sheep or cows, they have similar digestive efficiencies for the feeds for which direct comparisons have so far been made (French, 1970).

Goats have good ability to withstand both hot and cold conditions, provided the humidity is low. They are found in the humid tropics, but they do not flourish as well there as in the drier areas. It is generally conceded that goats have more tolerance to dry conditions than sheep or cattle. But they have been looked upon as the scourge of the whole dry belt through Africa and Asia, because often their grazing strips the lands of covering. Pakistan and several other countries have gone so far as to pass laws outlawing goats in the countries as an endeavor to stop the denuding of lands. However, few attempts have been made to enforce such laws because so many people depend upon goats for their livelihood.

The goat is kept in some areas primarily for milk and in others for meat and hides. In the Sind region of northwestern India, goats provide milk for cheese, the main supply of food and salable products; whereas, in the dry region of central Venezuela and northeastern

Colombia, meat production is of primary concern. In other places breeds such as the Angora are maintained for their coats. The Cutchi breed of Bombay state and the Sabel of West Africa are typical of the long-legged meat breeds (Figure 8.11). The fat percentage in goat carcasses lies between those of game and cattle. The goat carcass never attains finish as good as that of sheep because the fat is more concentrated around the viscera than in the sheep carcass. Goat meat is often preferred for this reason. The goat is intermediate between game and Zebu cattle in the relative proportion of the hindquarters to the whole carcass, but has a lower dressing percentage than either.

Among the best known of the milk breeds are the Jumnapari and Bari of India and the Nubian of Sudan. Groups of these goats have recorded lactations exceeding 200 days and 200 kg of milk; however, the average milk yield for most groups is less than 70 kg per lactation. Nevertheless, goats normally out yield sheep, although their milk is lower in fat content (3.5–4.0% in tropical breeds and 2.9–4.6% in temperate breeds). The repeatability of milk yield for goats has been reported as 0.41 in Switzerland and the repeatability of milk fat percentage 0.61. Unfortunately, little is known about the heritability of repeatability for goats in the N-S 30° area. One important characteristic of goats' milk is that the casein, during digestion, forms a less tough and more friable coagulum than the casein of cows' milk, so the digestive proteolytic enzymes penetrate and break it down more readily. This characteristic makes goat's milk preferable for some types of cheeses and relished for human consumption as whole milk.

The Toggenburg, Nubian, and Saanen are among the best milk producing breeds from the temperate zones. In recent years these breeds have been introduced to tropical areas to improve the milk yield of indigenous breeds. In general, there has been little selective breeding of goats in tropical regions, mainly because goats have usually been maintained by the lowest income groups of the sedentary population or by nomadic tribes. The latter give much more attention to selective breeding of their sheep than of their goats.

Goats reach maturity at 2 years of age but nannies may take the male from the age of 6 months if permitted. In well fed herds, females are mated between 12 and 20 months of age; but under poor feeding, mating is delayed until 24 months or later. Twinning is emphasized in some areas, but for the most part single births are preferable. Goats approach their mature weight from 2.0 to 2.5 times as rapidly as cattle in the tropics, but their gross energetic efficiency for milk production—that is, the ratio of milk energy to total digestible nutrients consumed—is approximately the same (French, 1970).

Where conditions are favorable, the production of a given volume

FIGURE 8 11
The Ouda goat is native to Nigeria It belongs to the group identified as West African Long-legged, which are found throughout the drier regions of northwestern Africa It is used principally for meat and milk production Its long, thin legs make it especially suitable for covering large areas to seek food (Courtesy J K Loosli, Cornell University)

of milk from cows is more profitable than an equivalent production from a larger number of goats. But as the nutritional plane declines, goats can obtain enough nutrients for some milk when sheep or cows would fail to do so. Given the potential of goats as sources of food for remote populations, it would seem that local governments and international agencies ought to give greater attention to development of breeds for meat and milk.

WATER BUFFALOES

Another important ruminant species for meat and milk production in some areas of the world is the water buffalo Since this species constitutes a very important segment of the livestock for several countries in the N-S 30° latitudes, Chapter 16 is devoted to its present contribution and some projections of its future role.

SWINE

Pig keeping everywhere is principally for the production of meat, although there may be some secondary products such as skins, bristles, and manure. Pigs are popular in the tropics. The world pig population is approximately 590 million, with around 34% of these in the tropics. Except where there are religious taboos against the consumption of pork, pig meat is relished by the sedentary populations. Little, if any, pork is consumed by nomadic or semi-nomadic peoples due to the problems of rearing pigs under their systems of animal agriculture.

Fifty years or more ago there were over 400 identified varieites of swine of some economic significance (Mason, 1951). At one time China alone had over 100 breeds, but by 1965 this number had been reduced to less than 40 (Epstein, 1969). Although the reduction in the number of breeds has been most dramatic in China, which had probably the greatest number of breeds for a single country, similar reductions have taken place throughout the world. Many local types have practically become extinct over the past 25 years with the expansion of commercial pig producing units. In many tropical countries, commercial pig production has developed near urban centers essentially by a transposition of temperate zone breeds and technology. As recently as 1950 Venezuela, for example, had little or no pork production; but currently the country is self sufficient in pork, mainly because of the sizable numbers of pigs kept under confined rearing systems in commercial units.

In most tropical countries there are still many pigs on small farms. These are largely indigenous types. Some are dwarf types, about 40 cm in height and 40 kg mature weight, while others are larger, 55–70 cm in height and 100 kg or more. Native types are generally characterized by a short, wide, and dished head with wrinkles at right angles to the sagittal axis; a short, broad body, somewhat sway back, pendulous belly, and reasonably well rounded hams, relatively soft bristles, and variegated color, although black is predominant. Their fecundity is usually as good as that of many of the improved breeds, and sometimes better; but their slow rate of growth, lower feed conversion efficiency, and excessive fat in the carcass as compared to present day temperate breeds have made them unpopular in pig producing units developed for maximum rate of output.

The initiation of progeny testing, the acceptance of crossbreeding, and the experimental evidence that traits respond to selective breeding have been the major factors in the vast changes from fat to meat type swine in the past 40 years. Although some efforts have

been made to develop new types in several countries, either through selective breeding or use of crossbred foundation, the new types have usually not performed as well as introduced stocks or crossbreds.

OTHER SPECIES

There are numerous additional species found in the N-S 30° latitudes that serve man's needs to a significant degree. These include the camel, horse, ass, yak, alpaca, and llama, whose major role is transportation but they also serve as producers of meat, milk, and fiber.

The camel is used in arid regions because of its ability to survive on the fibrous vegetation and poor water supplies of these areas. There are about 12 million camels in the world, with over 86% of them in the warm climates. There are two main varieties: the single-humped (*Camelus dromedarius*) and the double-humped (*C. bactrianus*). The former is most numerous in the tropics. In general, camels have been accepted and utilized with little or no attention given to selective breeding, although in some countries limited efforts are now being made to improve size, growth rate, and milking ability.

There are over 400 breeds of horses of some economic significance in the world, with nearly half of these indigenous to the tropics (Mason, 1969). Since horses are highly esteemed in most areas, they have experienced more selective breeding than almost any other species indigenous to the tropics and subtropics. Under even primitive conditions, selective matings have been practiced based particularly on wide use of stallions identified as superior for speed, endurance, or phenotypic confirmation. At present in the tropical areas selective breeding is being carried on chiefly by individuals or particular groups. Little, if any, attention is being given to selective breeding by governmental organizations.

The ass is found in significant numbers in many tropical countries. It originated in southern Asia but has emigrated widely, and currently several types can be identified. Often the ass is termed "the transport of the poor." Since it has not been glamorized like the horse nor been a significant contributor to meat and milk supplies, it has received little or no attention from animal breeders.

The yak of the 30° latitudes is found only in the Himalaya region. It serves as a quadruple purpose beast: a producer of meat, milk, and fiber, as well as a beast of burden. As compared to the cow and buffalo, it is a rather poor milk producer and its meat is coarse. It moves at a very slow pace, but its hardiness—that is, its ability to

survive under poor conditions, such as when the terrain is covered by snow—makes it acceptable in the highland regions. Its hair can be woven into clothing, tent covering, and other necessary items. Crosses of the yak with cattle, although the males are sterile, are preferred in several areas because of their greater speed and larger size.

The alpaca, llama, and vicuña are native to the Andes region, near the equator, in the western part of South America. Their habitat is usually above 3500 meters elevation. Like the yak, they serve as all around utility animals for certain peoples. The alpaca benefits considerably the economy of Peru, mainly by its wool. Because of its special characteristics, the wool does not compete with synthetic fibers as does sheep's wool. These species seem to have an inherent capability of utilizing forages grown at high altitudes; hence, they are more suitable than sheep or goats for the region.

The vicuña is essentially an undomesticated species. It is smaller than the alpaca but produces an exceptionally fine wool at the rate of about 0.25 kg per year. At present, the vicuña is in danger of extinction from predatory animals and indiscriminate hunting. There are fewer llamas than alpacas and their wool is of inferior quality. The llama is larger than the alpaca or vicuña so it contributes more to meat production and transportation. All three species have poor fecundity, but research is underway to find ways of improving it.

In certain areas rabbits and guinea pigs are kept as meat animals. The latter are widely used in areas of Peru.

Poultry, including ducks, geese, turkeys, and pigeons, collectively provide nearly as much animal protein as any other group. However, they can not be given fair treatment within the scope of this text; their description must be left to others.

Other current and potential sources of animal protein are the undomesticated species covering much of central Africa. In recent years a number of writers have argued that this great resource of protein for humans should be given much greater attention (Ledger *et al.* 1967).

POSSIBLE GENETIC DIFFERENCES WITHIN SPECIES

The foregoing description of species and some of their general performance characteristics indicates that the average level of performance of most stocks indigenous to the N-S 30° latitudes is much lower than that of temperate zone stocks. Clearly most parts of the warm climate region is a substandard environment for productive

livestock enterprises. But genetic differences may also be significant. Before breeding programs are initiated for tropical livestock further consideration must be given to two questions: (1) Is there real evidence of genetic differences in performance characteristics among the breeds or types available or is poor performance due largely to environmental influences? (2) And what is the importance of interactions between genotype and environment when stocks are introduced from outside?

Figure 4.5 illustrated that under the same environmental conditions, Indian Zebu cattle and their crosses with European breeds have limitations in the relation of total feed energy to milk output as compared to Holsteins. The average milk yield for many indigenous stocks is given as 200–900 kg per lactation. At the other extreme are averages for herds in the temperate zone that exceed 6800 kg per lactation. The highest recorded herd for milk yield among native stocks to date has been the Sahiwal herd at Pousa, India, with an average of 2270 kg per cow per lactation. This herd has been subjected to selective breeding and maintained under much better husbandry conditions than most herds in India. Although individuals in this herd have produced more than 4500 kg of milk, the range is from about 900–4500 kg.

Figures 8.12–8.15 show the distribution of lactation milk yields for four breed groups indigenous to Latin America, Ethiopia and India. In Table 8.2 is a summation of the means for various traits of the four breeds (Figures 8.12–8.15), plus Deshi (Figure 1.5). There are large differences among the 5 breeds for milk yield per lactation, length of lactation, calving interval, and age at first calving. On the average, the two breeds from Colombia have been poorer in milk yield than the three Zebu breeds (Harro, Hariana and Deshi), but they showed advantages over the others in length of calving interval (393 days) than the Zebus, 463 days. And they tended to calve at an earlier age.

The intra breed variability for most traits was high; e.g., coefficient of variation for milk yield was 31% for Hariana and 66% for BON. This degree of variation is 2–4 times higher than values reported for European dairy breeds (Rice *et al.*, 1967). The high variability contributes to the poor average performance of the indigenous breeds but also indicates opportunities in improvement for milk yield through selective breeding.

The sizable percentages in the CCC and Harro herds from which no milk was obtained shows these cows did not respond very well to the handling required for milking. Only in the Hariana herd were the majority of the lactations >500 kg of milk. The length of time the

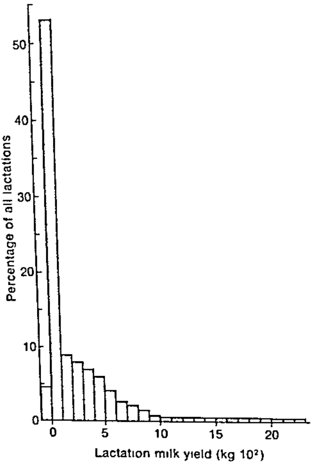

FIGURE 8 12
Distribution of milk yields by 100 kg intervals for 1357 lactation records on 514 Blanco Orejinegro (BON) cows at the Instituto Colombiano Agropecuario, El Nus Colombia (elevation about 1000 meters and dry season 4 5 to 5 5 months) (Data from Pearson *et al* , 1968)

animals were non-lactating was high. Expressed as percentage, the indigenous groups did not produce 37–81% of their life (Table 8.2) as compared to 10–15% in well managed dairy herds in the U.S.

Viability as measured by the percentage of females born that lived to complete at least one lactation was low in all 5 breeds (Table 8.2) as compared to >70% for dairy herds in the temperate zone. Generally, 20% or more died between birth and three months of age, although in some years up to 60% of the calves were lost from an outbreak of foot and mouth disease (Ngere, 1969). Most of the time another 20% of the females have to be sold between 3 months of age and first calving due to poor development as a result of diseases and

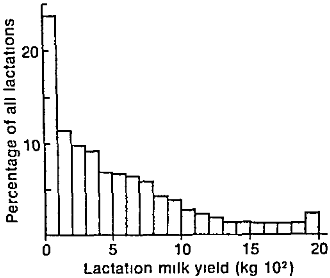

FIGURE 8 13
Distribution of milk yields by 100 kg intervals for 949 lactation records on 407 Costeño Con Cuernos cows (CCC) at the Instituto Colombiano Agropecuario, Turipana, Colombia (elevation 25 meters and dry seas of 5 months)

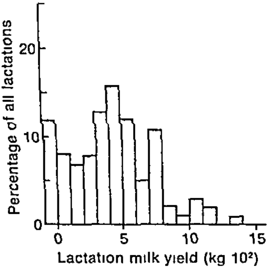

FIGURE 8 14
Distribution of milk yield by 100 kg intervals for 123 lactation records on 83 Harro cows (*Bos indicus* type found in Northern Ethiopia) at the Imperial Ethiopian Government Institute of Agriculture Research, Holetta, Ethiopia (elevation 2400 meters and dry season of 5 months) (Data from IRI, 1968)

parasitism. Losses from the cows of lactating age averaged 20–23% in these herds as compared to 5–10% in the northern latitudes.

Even though low energy intakes and other environmental variables were factors contributing to performance of the 5 breeds, it is unlikely that the environments of local farms would be superior. More often it is much, much worse. For instance, a survey made in Sierra Leone indicates that the average household must maintain a herd of 21 head of all ages to provide the family's milk needs.

Although having the calf present during the milking process in the herds described appears to have contributed to higher yields in

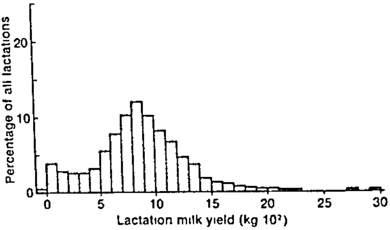

FIGURE 8.15
Distribution of milk yields by 100 kg intervals for 3827 lactation records on 1460 Hariana cows at the Central Livestock Research Cum-Breeding Station, West Bengal, India (elevation 100 m and dry season of 7.5 months). (Data from the Ph.D. thesis of L. O. Ngere, Cornell University, 1970).

TABLE 8.2
Summary of various traits of 5 tropical breeds of cattle

	Blanco Orejinegro (BON)	*Costeño Con Cuernos (CCC)*	*Harro*	*Hariana*	*Deshi*
Years	1956–65	1959–64	1965–68	1952–66	1956–68
Cows (number)	514	407	83	1460	336
Records (number)	1357	949	123	3827	1405
		TRAITS			
Lactation milk (kg)	220	481	504	842	412
Milk yield					
Average per day (kg)	2.0	3.3	3.1	2.9	1.6
% with no yield	4.5	23.5	12.0	0.5	0.7
% with yield <100 kg	58.0	35.0	20.0	4.5	5.0
% with yield <500 kg	87.0	60.0	60.0	16.0	70.0
Calving interval (days)	372	422	366	482	419
Lactation length (days)	102	147	169	257	251
Dry period (days)	303	258	–	243	141
Percentage of life dry[a]	81	64	–	44	37
Age at first calving (months)	41	39	50	51	45
Percentage born alive and completing first lactation	49	–	48	50	49

[a]Percentage of time in the herd after first calving in nonlactating state

spite of exclusion of the milk consumed by the calf, the use of the calf is an inefficient procedure both from the standpoint of labor requirements for milking and the detrimental influence on yields when the calf dies. The Hariana herd had 529 lactations in which the calf died early in lactation. These averaged 713 kg as compared to 915 kg for lactations of 200 days or more without calf loss. Of the cows that dried off prior to 150 days, about one-half had lost their calves. The loss of milk due to attachment of the calf, coupled with the indication that suckling may increase the length of calving interval and the problems of temperament toward the milking process, suggest that the traditional method of calf handling is another serious deterrent to the merit of these 5 breeds for commercial dairy enterprises (McDowell, 1971).

If it is assumed that a milk yield of about 2500 kg is presently a reasonable estimate of the best merit of selected native stock in a good environment, then it would be reasonable to assume that 50% or more of the difference between the cattle indigenous to the tropics and European breeds may be attributed to differences in inherent ability for milk production (Figure 8.16).

The average daily gains for cattle kept for the production of meat in many of the tropical areas are 0.15–0.25 kg from birth until time of sale, as illustrated in Figure 1.2. There is evidence, however, that when indigenous stocks, such as the Boran cattle of Africa and the Romosinuano of Colombia, are given good feeding and management these breeds will average up to 0.68 kg gain per day from birth to sale (Figure 8.16). The average dressing percentage for most indigenous groups ranges from 37–47% depending upon age and condition at time of slaughter, in contrast to 53–55% for the Boran and Romosinuano on good feeding and 55–63% for European types in temperate areas. This suggests that environment contributes significantly to the differences between the lower and upper potentials of the groups of cattle available for beef production at the present time.

The average yields of eggs and wool for native breeds is exceedingly low as compared to U.S. yields (Figure 8.16). Approximately one-third of the difference seems to be due to genetics and possibly two-thirds due to environmental influences, based on the performance of selected native groups under good feeding regimes. Many examples could be cited, but the preponderance of the evidence indicates that under reasonably good husbandry conditions, there are genetic differences between indigenous and other stocks in a number of traits of economic importance. Traits showing large genetic differences are milk yield, birth weight, rate of daily gain, mature body weight, length of lactation period, length of dry period, age at first calving, calving percentage per year, and intra breed variation for yield traits.

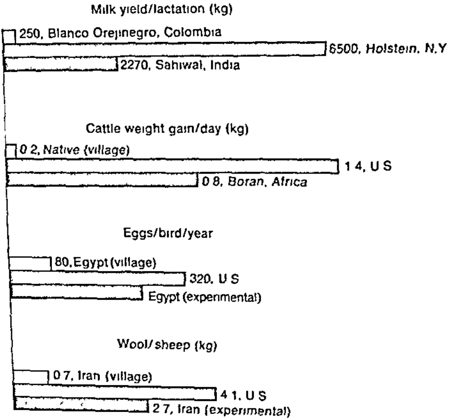

FIGURE 8 16
Comparison of average performances for native groups with averages for selected native groups under good feeding and management and averages for U S groups The lightest tone on the graphs represents the unselected native groups and the darkest tone, the selected native groups

Traits that give some indication of genetic differences are rate of daily gain, gestation length, generation interval, and dressing percentages. Differences in the efficiency of feed utilization seem to depend principally on the level of feeding. At low levels of feeding the native types are normally superior, especially when coarse roughages are the main component of the diet. At high levels of feeding the improved types are far superior in gross feed efficiency (input-output ratio). The foregoing are only estimates because the published measures of productivity for different groups generally relate to specific environments. The only means of arriving at true estimates of genetic differences would be to make different breed groups contemporaries in the same environment. But this would be costly. Hence the best estimates are derived from crosses of imported stocks with indigenous ones (see Chapter 10).

INTERACTIONS OF GENOTYPE AND ENVIRONMENT

Prior to about 1940, the spread of a type or breed of livestock beyond the confines of its area of origin was determined less by the merits of the animals as compared with those available in another area, than by such incidental factors as the availability of particular animals, custom, and the ability of animals to accompany their owners on long migrations over land routes. But since 1950 genetic improvement has been the major emphasis for importing livestock from the temperate zone into the tropics. The influence of temperate zone breeds, notably cattle breeds, has increased vastly—especially since the advent of frozen semen. This trend raises several important questions: (1) Should the natural selection imposed on native livestock by the tropical environment and the selection applied by certain livestockmen over the years be ignored or annulled? (2) Should livestockmen in the tropics concentrate on selective breeding for genetic improvement instead of attempting to adapt animals from outside? (3) Can groups of animals with potential for high performance in one environment be expected to do as well in another? The appropriate answers depend mainly on the extent of the interactions between genotype and environment. If these interactions are very significant, producers might better concentrate on selective breeding of native stock; but if the interactions are small or nonexistent, they would do well to upgrade the genetic potential of their stock through the most rapid means possible. The variations in economic and social circumstances will, of course, be strong underlying issues in determining which type of animals will be most appropriate.

The extent of the interactions between genotype and environment is difficult to determine with large animals because of the complicating factors of environmental fluctuations and management practices, including efforts made to control or restrict disease. If we measure the interactions in terms of value of end product, we must consider the important effects of marketing and consumer preference. In fact, genotype-environment interactions should probably be looked at from the standpoint of economics.

Dairy Cattle

There is not much experimental evidence of genotype-environment interactions for dairy cattle. Most studies in temperate climates have not shown important sire × location or herd effects. VanVleck (1963)

found that the genetic correlation between half-sib sets in herds stratified into four different management levels from 0.93–1.0 for both milk and fat yields was that AI (artificial insemination) sires would have similar rankings regardless of the production level of the herds in which their progeny were located. Another study gave high correlations between paternal half-sibs, when one group was located in the southern U.S. and the other in the northern U.S. (Lytton and Legates, 1966). Evidence from the subtropical portion of Louisiana has shown that progeny of sires proven in northern U.S. ranked in the same order in Louisiana herds as in the more temperate area. The ranking of sire progeny of U.S. Holstein sires used in Puerto Rico and Venezuela further confirm that sire × location effects are not important for Holsteins.

The progeny of 40 bulls from AI studs in the U.S.—at least 1000 AI daughters per bull—were classified into four groups based upon milk yield level of herdmates. Correlations among sire progeny yield averages at the different herdmate levels were all very high and indicated that bulls ranked in about the same order at all levels. No evidence of a genotype-environment interaction was found (McDaniel and Corley, 1967).

Experiments in Tennessee, comparing the progeny of Jersey and Holstein sires receiving either an all roughage ration during first lactation or roughage plus concentrates, showed that less than 4% of the variance was associated with sire × ration interactions. There were, however, significant differences among sires in the ability of their offspring to consume roughage. Experiences at Iowa State University with identical twins on high and low levels of feeding showed that pair × ration interactions were negligible for production and growth traits.

Evidence from dairy herds in Louisiana has shown that although differences among herds in the numbers of abortions and stillbirths are significant, the sire × herd interactions are not significant. The fact that the total percentages of abortions and stillbirths (4.3% and 3.1% respectively) in the Louisiana herds are similar to those in northern herds suggests that these problems are related more to the herd than to the climate. The average number of lactations initiated by the cows during a lifetime in Louisiana dairy herds (3.7) also parallels results from the northern part of the U.S. (Thomas *et al.*, 1968).

Although evidence from studies of European type cattle in the subtropical portion of the U.S. and certain areas of Latin America suggests that genotype-environment interactions are unimportant, this does not mean that they would be unimportant if the contrast between the native environment and the new environment were

greater. As a matter of fact, the environments under which genotype-environment interactions have hitherto been studied are not as extreme as tropical environments. Certainly there is much evidence that European type dairy breeds would perform poorly, even fail to survive in many tropical environments (Figure 4.5). Data from India show that when the proportion of inheritance from European breeds reaches the $^3/_4$ or $^7/_8$ level in crosses, performance is lower than for $^1/_2$ or $^5/_8$ European breeding. Similarly, pure European breeds have not performed as well as $^1/_2$ or $^5/_8$ crosses in several tests (see Chapter 10).

In peasant farming it might be a matter of having a little milk from the local type cattle or no milk at all if the local type were replaced with an improved breed. This clearly implies an interaction between genotype and environment. With sufficient feed supplies and disease control indigenous cattle will not exceed the performance of European breeds, indeed, they are likely to be inferior. Thus the type of environment can be used as a general way of identifying useful genotypes.

For areas where the feed supplies are limited and where disease and climatic stresses are unlikely to be mitigated, indigenous cattle or cattle known to be able to survive and produce in a given environment would be needed, especially when they have to be kept under extensive systems of management. On the other hand, under intensive systems (with good feeding and management) genotype-environment interactions are probably much less important. Detailed studies of the results of grading up of the Small East African Zebu to the Sahiwal breed on some farms and the successful use of purebred and high-grade Ayrshires, Guernseys, Holsteins, and Jerseys, on other farms for dairy enterprises in Kenya, confirm such conclusions. From these experiences the Sahiwal will provide a satisfactory first stage for grading up the Small East African Zebu to a more productive level in areas of medium agricultural potential. But a second stage that is grading up to produce $^1/_2$ to $^3/_4$ of one of the European breeds, will be better if the level of feeding and management attained by the stock owners at the end of the first stage is reasonably good and the climatic conditions are not too severe. Where husbandry remains poor, disease and parasite control have not been perfected, and feed supplies are inadequate for grades of European breeding the second stage should not take place. Purebred and high grade European breeds of dairy cattle have been introduced successfully into the improved peasant farms in Kenya, Tanzania, and Uganda, which have been declared free of East Coast Fever. These introductions have been especially successful in the higher altitude zones (eleva-

tions > 1500 meters). Lactation yields for these cattle in Kenya ranged from 2228 to 3132 kg per cow per lactation. These yields compare favorably with yields of some of the more advanced dairy countries.

Beef Cattle

"Beef cattle" is the term used to designate cattle kept essentially for the production of meat, but for most of the tropical world it is a misnomer because meat is the end product after the animal has served an initial purpose of milk or draft. Since there is a current emphasis on expanding animal protein from beef, the ensuing discussion emphasizes beef production as a speciality. Unfortunately, as with dairy cattle, the scientific evidence for interactions between type of animal and environment comes from temperate and subtropical areas.

There have been indications of differential responses to difficult environments or inadequate rations by various lines or strains of cattle of European or European × Zebu crosses. But the importance of these apparent interactions and the susceptibility of these groups to selection for superior performance in specific environments is not yet clear.

Evidence from Florida, where Shorthorn sires were bred to Brahman, ¾ Brahman–¼ Shorthorn, and half-bred females; and Brahman sires were bred to Shorthorn, ¾ Shorthorn–¼ Brahman, and half-bred females, showed that interactions between breed group and level of nutrition were important for 205-day weaning weight, percentage of calves born, and percentage of calves weaned. At the low level of nutrition, the ½ cross calves from Brahman dams were 30 kg heavier than calves of the same breeding out of Shorthorn cows. At the high level of nutrition, the difference between these two groupings was only 14 kg. Calves from crossbred cows were about the same weight as those from Brahman cows, but both groups were larger than calves from Shorthorn cows. In both percentages of calves born and percentage weaned, Brahman cows exceeded Shorthorns at low and intermediate nutritional levels. On high feeding, the Shorthorns were superior. These experiments show an interaction of breed and feeding for several economically important traits. In Texas and California, Brahman and Brahman crossbred cattle gained more rapidly than Herefords in the summer months, but the pattern was reversed in the cooler months. This demonstrates another type of interaction.

There appear to be definite interactions between genotype and environment for Zebu and European type cattle. The choice of the most suitable type or combination for a given environment must take into account both efficiency of production and quality of product. Oftentimes some compromise may be necessary when types are not available with maximum potentials for both.

Where cattle are expected to produce under extensive systems or on native ranges in the tropics, no doubt a Zebu type or another indigenous type is likely to give the best performance from the resources available. If the range consists of native grasses plus some improved variety or a legume-grass mix, a Zebu × European cross will perform best. Improved cattle breeds and improved feed supplies go hand-in-hand, as better type cattle will usually be required to provide returns from the increased investments. When continuous grazing of improved grasses with fertilizer is available, high grade European types will in all probability give the greatest returns. Hence, as with dairy cattle the level of environment will largely determine the most suitable genotype. As pointed out in Chapter 5, another important consideration in selecting the genotype, when feed supplies are limited, is inherent body size. Herein lies one of the major advantages of Zebu or indigenous types when feed resources are restricted.

Although some progress has been made in determining suitable genotypes for some situations, application should be tested before sweeping recommendations are made. As indicated above, the Criollo type cattle have largely been replaced in northern South American and Central American countries with gradations of Zebu. No doubt the first generation cross showed improvement over the local types, therefore the natural course was to add more Zebu breeding. At present there is some question as to whether the gradation to Zebus did not move too rapidly. Evidence from Colombia shows that extraction rates (number sold per 100 animals maintained) are lower than some years ago probably due to the poorer breeding efficiency of the Zebus. It is not clear whether the current lower results indicate calving percentage is due to genotype of the Zebus for reproductive efficiency or to environmental effects. The Zebu tends to wean a larger calf than the pure Criollo, but when overall efficiency is made on kilograms of calf per cow exposed for breeding each year, the advantage of the Zebu is subject to challenge. Experiments in Venezuela indicate the Criollo cow is a better mother and will wean more kilograms of calf per year than the Zebu (see also Chapter 10). So vast changes to the point of extinction, or near extinction, of a genotype may not always be wise.

Sheep

Experiments with five strains of Merinos, reared for a number of years in three wool growing regions of Australia, exhibited some evidence of interactions between location and amount of wool, body size, and reproductive traits, but not enough to be important in the choice of breeds for particular areas of Australia. This implies that in selecting the Merino, type of body covering, size, and reproductive performance are more important than area of origin (Dunlop, 1962).

In the southeastern U.S. an interaction has been found between breed type and location. The medium wool meat types (e.g., Hampshire) were lower in percentage and weight of lambs weaned per ewe bred than fine wool crossbred ewes (e.g., Merino-Rambouillet) under warm, humid conditions of Florida and Louisiana than in the cooler climates of Virginia and Kentucky. Another type, a group originating in Florida from imports in the 16th century, excelled both Rambouillets and Hampshires in lambs weaned per 100 ewes bred in that state (Tech. Comm. S-29, 1966).

In Iran, Egypt, India, and other countries where attempts have been made to introduce breeds from northern Europe, the introduced groups have often failed to survive due to the severe environmental conditions, principally inadequate feed. On the other hand, first generation crossbred rams from the introduced and native types have given satisfactory performance, at least on government farms.

Iranian nomadic herdsmen place great importance on the rearing of their sheep—especially rams—under their usual flock environmental conditions. These herders normally refuse to accept young male lambs of the indigenous types selected from government farms because they have recognized that their sheep must be accustomed to the nomadic herding conditions. How much this opinion has to do with identifying the best genotype and that associated with having the ram adjusted to poor feed conditions early in life needs further evaluation. This point is discussed later in Chapter 15.

Swine

Experiments in the temperate zone indicate that genotype-environment interactions in swine may be important for determining balanced rations, levels of nutrition, efficiency of feed utilization, and response to certain management regimes. Where improved breeds have been introduced into the tropics, the number of breeds involved has not been sufficient to determine if such interactions are important. The

one clear interaction in the tropics is the morbidity and even mortality from the effects of solar radiation on pigs with white hair and light pigmented skin. This had led to best acceptance of breeds with a high proportion of red or black coloring (Kristjansson, 1957).

A few tests comparing indigenous, improved × indigenous crosses, and improved types of swine in the tropics have favored the pure improved types. These trials were conducted under good conditions of nutrition and management. But recent experiences in U.S. assistance programs in southeast Asian countries have shown that a pig of an improved breed turned loose to scavange around the household soon perishes, whereas the local types manage to survive. Although the improved breeds may be less efficient in performance in a tropical environment than in the U.S. (Chapter 4), commercial pig producers in the tropics have found the improved types and crosses among these types so superior to the local native types that, like the U.S. producers, they have changed almost completely to the use of the improved types or improved × native crosses.

Poultry

There have been more genotype-environment interaction studies undertaken with poultry than with any other species. Again most of the scientific evidence comes from the temperate and subtropical areas. Experiments in Canada, Japan, and the U.S. have not given any strong indication of differences within a strain due to location, nutritional level, or response to elevated environmental temperature, although there is evidence of differences among breeds due to these factors. The heavy breeds, such as New Hampshire, seem more responsive to variation in temperature and nutritional levels than White Leghorns. New Hampshires, Barred Rocks, White Leghorns, and jungle fowl were subjected to temperatures up to 30°C by California researchers in studies of acclimation to environmental temperature changes. Body temperature regulation was best in the jungle fowl, and egg production was reduced markedly in the two heavy breeds with rising temperature. The White Leghorn excelled all other groups in feed efficiency and egg production, however.

As with swine, the improved breeds suffer severe consequences when they are relegated to the role of scavengers about the village households. But the far superior inheritance for rate of growth, egg production, and efficiency of feed conversion has led to almost universal adoption of the improved types for commercial production in the tropics.

Currently, the general conclusion is that for all types of livestock there is ample evidence that genotype-environment interactions exist where environmental conditions are poor and when differences in inheritance for performance characteristics are large. When large genotype-environment interactions exist, it may be necessary to give a great deal of attention to selection of the best genotype. But do we have time to explore all the possibilities? This question has been answered in the negative throughout most of this book. Flexibility is recommended rather than the acceptance of one genotype as necessarily most suitable for a given environment. For instance, currently in the isolated Llanos region of Venezuela and Colombia, it does not pay to introduce improved animals or managerial skills. But if a roadway were opened from Caracas to Bogota, increased land values would necessitate higher levels of inputs, including better stock. Thus each situation needs constant scrutiny in the light of economics in order to determine which method of approach would be best—to change the environment or to change the animal. Changing the environment generally requires time and investments, but changing the animal—except for outside introductions—takes much longer. In the long run, changing the genotype is expensive. The selection of genotype must be based essentially on the nutritional and managerial levels of the environment. The available evidence, even though scanty, clearly indicates that the most important questions facing livestock producers in the tropics are: (1) what would be the most suitable genotype; and (2) how to go about obtaining these through systems of breeding? The next two chapters will explore these questions.

It should be pointed out that there is a need for continuing research on livestock breeding in the tropics. Current genetic research, substantial as it is, is based largely on experience in the temperate zones. We especially need to know what the indirect effects or correlated responses of other traits will be if selection is made primarily for one or a few traits. For example, we require more evidence about genetic antagonisms that may seriously reduce genetic progress in a tropical environment if selection is directed exclusively to milk yield in dairy cattle.

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9

Improvement Through Breeding

In much of the temperate zone the use of the word "improvement" is readily understandable since it has become related to ongoing practices of professional breeders and a reasonably well defined end product, namely the kind of animal desired and the purpose it is to serve. We can, for example, project with reasonable accuracy for the next two or more decades the management systems that will be employed for commercial dairy production in the northern hemisphere. Therefore, we probably know in general terms the best breeding programs for dairy cattle. These will entail the use of sizable populations; making decisions about sires on the basis of information from fairly large progeny groups after the sires have been used in artificial insemination; and some restrictions to prevent too close inbreeding. Contrarily, in areas where there are few, if any, professional breeders and no organized systems of record keeping, the problems associated with undertaking animal improvement through breeding are entirely different.

Improvement also implies having a concept of the kind of products the animals are expected to produce and the type of environment in which they will live. Unless these can be described fairly well,

there is little to be gained by setting out an improvement program. Feed resources are the primary limiting factor in any livestock improvement program. Currently cattle are maintained in environments where the annual feed supply available per animal does not exceed 1000–1500 Mcal of energy equivalent per year. Under such circumstances, little of the genetic variability among groups or individuals within groups can be recognized because almost the entire feed energy is required for body maintenance. Unless 2500–3000 Mcal or more are available annually per head of adult cattle, even for small breeds, attempts to develop improvement programs are unwarranted. Similarly, sheep must have 400 or more Mcal and swine 800–1000 Mcal per head as a minimum requisite of an environment approaching suitability for breed improvement in the sense of increasing output per animal before genetic variances among individuals can be discerned with any degree of reliability. Certain measures to reduce the impact of disease are also required. If animal mortality is so great that all females which survive are needed to maintain herd or flock numbers, attempts at genetic change will be essentially futile. In short, the level of environment must be conducive to survival and reproduction at a sufficient rate for the population to increase, and yields of a usable product high enough to provide economic incentives to producers.

Areas already exist in all tropical countries where these minimum environmental conditions are being met. And these areas will no doubt be expanded. Consequently, it is important to consider further possible means of bringing about genetic improvement and the practicality of projected changes.

THE NATURE OF ANIMAL PRODUCTION TRAITS

Animal productivity (phenotypic expression of a trait) is the result of heredity or genetic makeup (genotype), the environment, and possible interactions between them. The measures of productivity of primary concern to livestock producers fall into two major classes: (1) those which measure usable products, such as milk, meat, wool, and eggs; and (2) those associated with the animal's capability to survive, reproduce, and expand in numbers in a given environment or "fitness characteristics." Some measures fall into both classes. Meat production represents an example, since animals slaughtered are in excess of those needed as replacements to maintain herd or flock numbers.

Genetic differences in performance are also of two classes (1) differences between groups, breeds, or strains, and (2) differences among individuals within a group Genetic variation constitutes the differences among groups and individuals within a group resulting from their genetic makeup, transmitted by their parents This variation, resulting from either additive or nonadditive gene effects, is the raw material with which the breeder has to work The amount of genetic variation is determined by the heritability of a trait × the total phenotypic variation in the trait Generally it is expressed in terms of the genetic standard deviation (σG), which is obtained as follows $\sigma G = h^2 \sigma p$, where h = heritability and σp phenotypic variation The genetic merit of a group of animals will average that of their parents About half will be genetically superior to the average of their parents, while an approximate equal number will be inferior The superior individuals provide the opportunity for genetic improvement through selection

As the livestock breeder endeavors to bring about change in geno type, he is concerned with two kinds of heredity—namely, qualitative and quantitative Such traits as horns vs polled condition, coat color, and certain abnormalities, are qualitative in nature Each trait is determined by a single pair of genes or only a few pairs of genes that have major effects—oligogenes Variation in such traits is largely genetic in nature, environmental effects are generally low In contrast, production traits are determined by many pairs of genes—polygenes—each of which has a minor effect, environmental influences on such traits may be large

TOOLS OF THE BREEDER

Selection is the process of deciding which animals in each generation will be allowed to become parents of the succeeding generation and the number of progeny they will be permitted to contribute In general, the objective of selection for qualitative traits is to accept or reject individuals according to an established standard—e g , accept an animal that is solid red in color but reject one that is red and white Since quantitative traits are complex, the objective of selection for any performance trait is to increase the frequency of the combinations of genes which provide the animal that is most suitable for a given environment and economic situation The best combination of genes is likely to vary between one environment and another The culling of animals that are poor in economically important traits tends to reduce the frequency of undesirable genes in a herd or flock If

these animals are replaced by others that are superior in the important traits, the frequency of desirable genes should be higher in the next generation.

FACTORS AFFECTING THE RATE OF GENETIC IMPROVEMENT

A number of factors have a direct bearing on the rate of genetic progress through selection. These include (1) phenotypic variation (genetic variation), (2) heritability of traits under selection, (3) accuracy of selection, (4) selection differential, (5) number of traits under selection, (6) genetic association among traits, and (7) generation interval. When selection is for a single or primary trait, the factors in the following equation should be considered:

$$\Delta\overline{G}_y = 0.5\left(\frac{r_{AI} i h^2 \sigma p \text{ for males}}{L}\right) + 0.5\left(\frac{r_{AI} i h^2 \sigma p \text{ for females}}{L}\right)$$

where $\Delta\overline{G}_y$ = average genetic progress per year, r_{AI} = correlation between breeding value (A), and selection procedure (I) or the accuracy of selection, i = intensity of selection given in inputs of the phenotypic standard deviation, h^2 = heritability of the trait, σp = phenotypic standard deviation of the trait, and L = generation interval in years. In this equation, sires and dams each contribute one-half (0.5) to the progress. Since the accuracy and intensity of selection are quite different for males and females, they are separated in the equation. The sections that follow describe components of the equation.

Heritability

The total hereditary variance ($\sigma^2 h$) can be divided into three parts: (1) the additive genetic variance ($\sigma^2 g$), (2) the variance due to dominance deviations ($\sigma^2 d$), and (3) the variance due to epistatic deviations ($\sigma^2 i$). The progress that can be expected in improvement of a trait by selection depends upon the ratio of the additive genetic variance to the total phenotypic variance. This ratio is termed heritability (h^2). It can also be defined as the fraction of the difference between the parents and their generation average that is expected to be transmitted to their progeny. Heritabilities for various traits can be estimated by using either the parent-offspring or the paternal half-sib relationships. The latter is most widely used. The higher the

heritability for a trait, the greater the potential rate of improvement More rapid progress could be made in selecting for increased birth weight ($h^2 = 40\%$) than for calving interval ($h^2 = <10\%$) Variation in levels of heritability is discussed further in other sections of this chapter and Chapter 10

Repeatability

Closely related to heritability is the value of repeatability For some characters—e g , the milk yield of successive lactations or the number of pigs per litter from the same sow—repeated observations are possible Use of all available observations can increase the accuracy of selection for characters affected by temporary environmental conditions by minimizing the effects of these conditions, thereby reducing errors in the identification of superior individuals

Repeatability is usually defined as the fraction of the variation that is attributable to permanent differences between individuals It consists of the variance due to additive genes, dominance effects, epistasis, and any permanent effects of environment on the animal that are different from those on its herdmates or flockmates Estimates of repeatability can be calculated as the correlation between the repeated results either in a usual correlation analysis or in an intraclass correlation by an analysis of variance The fact that the result from the same individual tends to repeat itself is to a certain degree natural and depends partly on the genotype, which is the same all the time, even though the activity of some genes may change with age in relation to certain environmental influences The magnitude of the coefficient of repeatability depends upon the variance due to permanent differences between individuals caused by environment and the variance due to temporary differences caused by environment which are randomly distributed between and within individuals This means the coefficient of repeatability includes all of the genotypic variation plus a portion of the environmental variation It therefore sets an upper limit for heritability

The accuracy with which the breeding value of an animal can be assessed is greater if it is based on the average of several observations than if it is based on a single observation The best estimate of real producing ability for a trait such as milk yield is expressed as

$$\left[\frac{nr}{1+(n-1)r}(\text{individual avg} - \text{group avg}) + \text{group avg}\right]$$

where n = number of records on the individual r = repeatability

If repeatability for milk yield is 0.50 and a cow had three records instead of one, we would anticipate that 75% of her superiority would be exhibited in a subsequent lactation. Use of the above formula permits equitable comparison among cows in a herd at a given time with varying numbers of lactations. Using this procedure to rank cows in a herd on the basis of their estimated producing ability is an effective means for arriving at decisions on culling or selection of dams of future sires. Repeatability values are also useful in beef cattle if selection is to be made on the basis of some trait such as weaning weight of calf.

By combining repeatability and heritability an estimate can be made of the predicted breeding value of an animal. For a trait such as milk yield the expression is:

$$\left[\frac{nh^2}{1+(n-1)r}\text{ (individual's avg} - \text{group avg)} + \text{group avg}\right]$$

where h^2 = heritability, n = number of records, $r \times$ repeatability.

The heritability of the average of n records (h^2n) is higher than the heritability of single records (h^2). However, since averages have a decreased variance, the possible selection differential is decreased by $[1+(n-1)r]/n$ when several records are used. Averaging records has the advantage of better precision in estimating breeding value, but has the disadvantage of lengthening generation interval because of the time required for the accumulation of data before selection can begin.

Accuracy of Selection

The accuracy or effectiveness of selection for a trait may be defined as the correlation between true breeding value (T) and the selection procedure (I) or as r_{TI}, where r_{TI} is the breeder's accuracy of estimating the genotype or breeding value of an animal. Accuracy of selection is measured by h, which is the square root of heritability, $h = (h^2)^{1/2}$.

For maximum accuracy of selection the correlation between the average breeding value and the variable(s) on which selections are based should be as high as possible. The heritability of a trait and the correlation between breeding and phenotypic values are directly related, since $h^2 = (r_{AP})^2$, which represents the fraction of the phenotypic variance associated with variation in average breeding values. Thus $r_{AP} = (h^2)^{1/2} = h$.

Selection Differential

The selection differential is the difference between the selected individuals and the average of the group from which they were selected. It is determined by the proportion of the progeny needed for replacements (numbers to maintain or expand herd or flock size), the number of traits considered in making the selections, and the differences that exist among animals in the group. In other words, the magnitude of the selection differential contributes a great deal to the intensity of selection. Selection differential is expressed in phenotypic standard deviation units (i) as $S/\sigma p = Z/p$, where S = selection differential, σp = phenotypic standard deviation, Z = the height of the normal curve at the point of truncation or where the selected individual with the lowest record falls, and p = the proportion of the population saved or selected.

When efforts are being made to select for several traits simultaneously, it is better to express the selection differential(s) in units of the phenotypic standard deviation and call it the intensity of selection (i). In this type of selection the intensity of selection becomes $i = S/\sigma p$, where S = selection differential and σp = phenotypic standard deviation. If $S = 1\ \sigma p$, then $i = 1.00$.

Number of Traits

When the purpose of selection is the exclusion of a single trait that is controlled by a single pair of genes, and all animals showing evidence of that trait are not allowed to contribute future progeny, rate of genetic improvement can be high. Even in the case of a quantitative trait, such as milk production, fairly rapid improvement can be made if this is the only trait under consideration. Unfortunately, in practice one trait can rarely be given all possible emphasis because the total economic value of an animal almost always depends on several traits—e.g., in dairy cattle enterprises milk yield, milk composition, and fertility are all of economic importance even though the breeder may be placing his primary emphasis in selection on milk yield. Consequently, the breeder is forced to consider several traits in his selection. Although this is the only possible way to increase total economic value, it decreases progress in individual traits. The magnitude of the decrease depends on many factors, but primarily on the closeness and direction of the genetic correlation between traits, the number of traits considered, the weight given to an additive trait, and the selection method used.

The average reduction in progress in each trait, when several are considered is approximately $1/\sqrt{n}$, where n is the number of traits under selection. If four genetically independent traits are considered at one time, the selection differential for each of them will be about half the amount for only one trait, $1/\sqrt{4} = 1/2$. This calculation assumes that there are no genetic associations—favorable or unfavorable—among the four traits.

The low reproduction rate of sheep, cattle, and buffaloes, and the large number of traits of economic importance usually needing consideration in the selection process, place rather serious limitations on the selection differential for various traits. For these reasons, selection should be directed only toward the traits of real importance. This is especially true when the traits have a low degree of association, such as coat color and milk yield.

Genetic Association

The genetic association between two traits—e.g., milk yield and milk fat percentage— is the correlation between the gene effects influencing them. Genetic correlations are caused principally by pleiotropy, the influence of a single gene or locus on more than one trait. Another, transient cause of genetic correlations may be the linkage of genes that influence the traits.

If the genetic correlation among traits is favorable, the rate of general improvement is enhanced. Conversely, if there is antagonism among the traits, the rate of improvement from selection is reduced. Thus far, no major unfavorable genetic associations have been identified in most species of livestock. Of course, such associations may yet be discovered as more is learned about indigenous stocks of the tropical world and genotype-environment interactions. Several relationships between traits have been found to be slightly negative—milk yield and milk fat percentage. In European breeds, there has been a tendency for milk fat percentage to decline with increasing milk yield, but this has not proven serious.

Generation Interval

The generation interval is the average age of all parents when their progeny are born. In most groups of cattle this is from 4 to 7 years, depending on the age of first calving and the age at which the males are placed in service. The generation interval is frequently longer in

males than in females. The longer the generation intervals, the slower the rate of progress by selection.

The gain in genetic value per generation for a trait is $\Delta G = r_{GG} D_{\sigma G}$, where ΔG = genetic progress per generation; r_{GG} = correlation between predicted and true genetic value; D = the intensity of selection per generation interval; and σG = the genetic standard deviation. Generally, the annual rate of genetic gain is relatively small for a trait (<2%) but this can vary widely depending on the generation interval. The average annual genetic progress for a trait is expressed as $(\Delta \overline{G})$ and is determined by ΔG/generation interval.

If, for example, the heritability for milk yield is 25%, the selected individuals (males and females) are 400 kg higher than the average of all animals, and the generation interval is 4 years, the rate of improvement would be $(0.25 \times 400)/4$ or $\Delta G = 25$ kg. But if the generation interval is 6.5 years, the annual gain $(\Delta \overline{G})$ would be about 15 kg. This illustrates the importance of keeping the generation interval relatively short.

Non-genetic Factors

The effects of the environment on the animal's performance are important non-genetic factors influencing rate of improvement. Even though attempts may be made to provide a relatively uniform environment, random environmental differences among animals will occur. Identical twins have the same genetic makeup but they may vary in their performance because of environmental differences, such as an udder injury, which might influence milk yield, or infestation by internal parasites, which might have occurred because one twin ate grass growing around droppings from an infected animal while the other did not.

Where there are marked seasonal changes—wet and dry seasons—the environmental differences may mask identification of superior genotypes. For instance, a calf or lamb born near the end of the wet season may be 30–40% smaller at 6 or 8 months of age than offspring born near the end of the dry season or early in the wet season. Consequently, every attempt should be made to subject all animals from which selections are made to the same environment as nearly as possible. This will result in a larger proportion of the observed difference among individuals being genetic and will increase the accuracy of selection. It is important to adjust for known environmental differences before making selections provided the environmental differences can be evaluated. Some can be reasonably well defined. It is

common practice, for instance, to make adjustments for differences in age of animals, age of dam, and sex in beef cattle herds and for age of calving in dairy herds.

BASES FOR SELECTION

The objective of selection is to bring about changes in certain characteristics. This transpires by culling the animals poorest for the traits chosen and keeping the best. This is simple in principle but proper execution is a very complex process. Selection is chiefly based on (1) individual performance or group performance, (2) pedigree information, (3) progeny tests, or (4) a combination of all three.

Individual or Group Performance

Selection based on the individual's own performance results in the highest rate of progress toward improvement when the heritability for the trait(s) is high. Growth rate represents an example. Selection on the individual's performance also allows the most rapid turnover of generations, thereby decreasing generation interval. It is recommended that individual performance be used for traits that have medium to high heritability and can be measured directly on the individual—e.g., milk yield, growth rate, and wool clip.

Family or group performance may be related to progeny tests, or to general selection programs. For a general program of mass selection, the animals in a given group would be sorted into groups based on their own performance for one or more traits. The expected gain by this procedure would be equal to $0.5\ h^2D$ or $\frac{1}{2}$ (heritability × selection differential). If the average weaning weight of calves from a herd were 160 kg and if the upper 50%—averaging 180 kg—were selected as replacements, the progeny would be expected to average $\frac{1}{2} \times h^2$ or $0.30 \times (180\text{–}160)$ or 3 kg higher than if no selection had been made.

Pedigree

A pedigree is basically a record of ancestry. In the past it constituted only the geneology of the animals related to the individual. This type of pedigree is of little value From a practical standpoint, knowledge of the performance of the parents is required if the pedigree is to be useful. More recently, inclusion of production information about

ancestors has also been included to make the pedigree more useful.

Record keeping is costly and time consuming, and when it goes beyond a single herd or flock it requires organizational structure. Due to insufficient numbers of trained personnel, inadequate communication and transportation facilities, and virtual non-existence of breed societies or organizations to maintain records, the primary requisites for deriving pedigrees are not currently available in a number of countries.

It can be argued that local record keeping is unnecessary following a decision to change the native stock by continuous crossing or grading up with importations of sires of improved breeds. This may sometimes prove true but as pointed out previously in the discussion of the grading up of native Criollo cattle to Zebus in several Latin American countries, the complete change of native stock may be a mistake. Another example comes from Iran, where Brown Swiss sires have been used for continuous grading up with native cattle. This has been pushed on a country wide basis. The milk yields of the first generation crosses were far superior to those of the native cattle. The process appeared promising, but the results were disappointing with the first and second generation of backcrossing to Brown Swiss because the performance of the latter group was very near the level of the indigenous group.

Pedigree information, including identification of parents and close relatives and some estimate of their performance, is well worth the effort when one considers that decisions on a mating to produce a male for use in a dairy herd are only confirmed through his progeny. This takes 5 or more years in the U.S. but 7 or more years where sires are not put into service until about 3 years and females do not calve for the first time until 3.5 years of age or later. Pedigree information is also useful in selecting among young animals before their own performance or their progeny's performance is known. It can serve too, in selecting for traits that are measured late in life, such as longevity and susceptibility to disease, or traits expressed only in one sex, such as mothering ability. In addition, good pedigrees are valuable in selecting against inherited defects, such as dwarfism or susceptibility to cancer eye.

In using pedigree information, only the nearest or closest relatives should receive extensive consideration, since the more distant relatives can influence the makeup of the individual only through the closest relatives, sire and dam. The performance of the poorer ancestors should, however, be considered along with the best performers because the influence of all grandparents is, on the average, the same. In short, in selecting animals from pedigree, the proportional weight-

ing is based on reliability of information. If, for instance, the sire of an individual has a reliable progeny test, then 50% of his estimated superiority is used as 1/2 the total weighting in the pedigree. The rest comes from the dam's side. The estimated superiority from the dam may be taken as 50% of her deviation from the herd average. Since a single record may be subject to serious environmental effects, if there is performance information on the parents of the dam, this should be included. A better procedure is to accrue the dam's contribution by crediting the dam with 10% of her deviation from the herd average plus 35% of the estimated superiority of the dam's sire and 5% of the maternal grandam's superiority over her herdmates.

After the individual has acquired a performance record, the pedigree evaluation is usually reduced to 33%, and 67% is credited to the individual's performance. The individual's superiority is estimated as 67% of her deviation from herdmates for the trait under consideration. The 33% pedigree portion is weighted as stated above. This is the procedure often employed by dairy cattle breeders. In beef cattle, pedigree selection on close relatives is considered about half as accurate as the individual's own performance record.

Progeny Tests

Progeny test information is the best for selection, if the information is adequate. Progeny tests are most useful in the selection of sires particularly when a trait can only be measured in one sex—e.g., milk yield. Also selection for traits with low heritability—e.g., calving interval—should be done through progeny test. The main advantage of progeny test information is accuracy. The disadvantages of progeny testing are the less intensive culling because of the small segment of the population that can be properly evaluated; the longer generation interval required to obtain test information; the lower accuracy as compared to individual performance if too few progeny are tested or the evaluation is not good; and progeny testing is expensive.

A correlation of 1.0 would reflect complete accuracy between estimated breeding value based on progeny test information and actual breeding value. A perfect relationship is not realized in large animals because of the limitations on number of progeny. A large number of progeny per sire are required in order to obtain progeny averages accurate enough to rank sires for their breeding value. The magnitude of the heritability is also a factor. The accuracy of selection on the basis of progeny average (correlation between estimated and actual breeding value) is illustrated by the following:

No progeny	Correlation between estimated and actual breeding value for h^2		
	$h^2 = 0\ 10$	$h^2 = 0\ 30$	$h^2 = 0\ 50$
1	0 16	0 27	0 35
6	0 36	0 57	0 68
10	0 45	0 67	0 76
50	0 75	0 89	0 93
100	0 85	0 94	0 97

When selection is for milk yield, progeny testing is the only means of evaluating sires in spite of its limitations But when the trait can be measured by the male's own performance—e g , growth rate—selection on individual performance is probably best unless there are several progeny per sire With heritability of 0 10, 0 30, and 0 50, progeny test information on one progeny is approximately one-half as accurate as information on individual performance About six progeny per sire are required to make progeny test selection approximately as accurate as individuals performance selection at the three levels of heritability

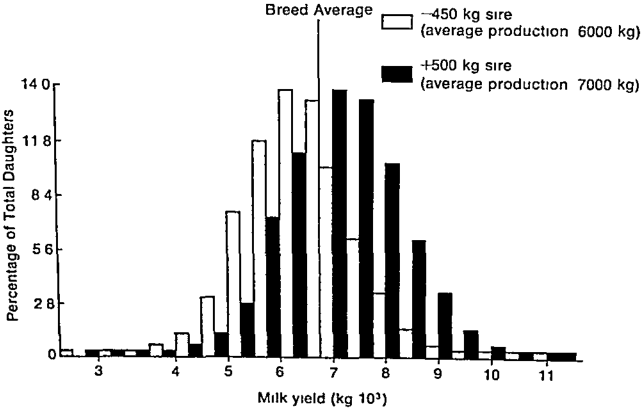

FIGURE 9 1
Production distribution of daughters of a −450 kg sire and a +500 kg sire (Adapted from Carter 1969)

It is desirable to have more than one sire being used at a given time in a herd or herds since the merits of a progeny test lie principally in the ranking of sires available at a given time. The larger the number of sires with a reasonable number of progeny, the greater the opportunity for a high selection differential.

Since progeny tests are based on the average performance of progeny, not all the daughters of a sire with a high plus proof will be above the breed or herd average for milk yield or all those of a minus sire below the average. The production distribution of daughters of a −450 kg sire and daughters of a +500 kg sire (Figure 9.1) illustrate the point. The poor bull will have some very good daughters, but the high plus sire will have more than twice the number of daughters with milk yields above the breed average.

In spite of its limitations, progeny test information should be used for all traits, especially traits of low heritability, traits that can not be measured on the individual, and traits expressed in only one sex.

Combinations

As guidelines for selective improvement, information gleaned from pedigrees, the individual's own performance, and progeny are all useful, but singly each has limitations. Each serves a purpose, but together they should be considered as building stones for the ultimate objective which is to utilize a combination of all three. In a sense each corresponds to a stage of life in the individual. Pedigree information can be used as a predictor before the animal is born. Individual performance comes at some later stage of life, the time being dependent on the trait used as a measure, and progeny test comes even later. Seemingly, the best policy would be to make initial selections on the basis of pedigree, followed by further selections on individual performance records, and final decisions on differential reproduction or the contribution a male or female may make in subsequent years determined on the basis of progeny test information.

TYPES OF SELECTION

In general, there are three recognized types of selection: (1) tandem, (2) independent culling levels, and (3) indices of merit (selection indices).

Tandem Selection

In tandem selection one trait at a time is emphasized; when the desired level of performance is reached, a second trait is emphasized, and so on. The major disadvantage of this type of selection is that if executed to the fullest extent, some animals poor in other traits essential to their functioning in a given environment may be retained as replacements. It is therefore not recommended for most farm livestock.

Independent Culling Levels

Selection based on independent culling levels requires that rather specific levels of performance be attained in each trait in order for an animal to be retained as a replacement. This system can be effective but has the disadvantage of not allowing slightly below standard performance in one trait to be compensated for by superior performance in another. For example, the independent culling levels among females in a dairy herd might be +100 kg milk yield and +0.1% milk fat test over the group average. These criteria would require rejection of a cow with +300 kg of milk and −0.2% milk fat test. If there was interest in increasing the herd milk yield as rapidly as possible, progress would thus be slowed by rejection of the cow with a high superiority in milk yield.

Selection Index

The use of an index of net merit gives weight to various traits in proportion to their relative economic importance, the heritabilities of the traits, and the genetic association, if this exists, among the traits. Generally this is the most effective type of selection procedure since it allows slightly subpar expression in one trait to be offset by outstanding performance in one or more others. In the example above, the +300 kg superior cow would probably be considered as satisfactory replacement on the basis of a selection index. Also, by giving weightings to traits of higher heritability or greater economic importance, this system increases net merit.

The selection index should be restricted to as few traits as necessary and to those with a reasonably good level of heritability. The larger the number of traits included, the slower the progress in any

single trait. Differences in heritability should be considered in selection in order that there be an opportunity for selection on traits which will respond. If a trait has an extremely low heritability (less than 10%), little genetic improvement can be recognized in a few generations. *Giving such a trait emphasis reduces the emphasis that could* be given to traits with greater potential for response (heritability of 20% or higher). While traits of low economic value in relation to yield, such as hair coat color or shape of horns, should be given little or no attention in selection for performance, all heritable traits of economic value *ought to be considered concurrently*. The attention they receive is determined by their relative economic value and their heritability.

Although selection on the basis of all economically important traits simultaneously will result in the most rapid improvement in genetic merit involving all traits, it may be preferable, in the early stages of selection among indigenous stocks, to give primary emphasis to selection on a single expression of performance. If milk yield, ability to let down milk without a calf present, temperament, lactation length, and calving interval were all traits needing emphasis, selection of females on milk yield alone, when the cows are milked without the calf present, would most likely give adequate emphasis to the other traits in the early phases of a selection program. Obviously, this would be simpler than attempting to employ a weighting procedure for each trait.

For improvement through selection, the trait or traits must be characterized. The more precise the measure the better. In recent years, the technical literature has abounded with recommendations on selection of animals in a tropical environment for "adaptation." This is not a single identifiable trait, but rather an overall assessment of the animal's response to the environment, which varies with the acceptable standard established. About the only time adaptation becomes a single trait criterion is when the conditions of the environment—either feed supplies or disease—are so acute as to make survival the primary factor. On the other hand, cattle with a low growth rate—e.g., 0.4 per day from weaning to time of sale—may be acceptable in one environment and thus considered adaptable, but unacceptable in another. In short, selection differentials expressed as deviations from individual herd or group averages are advisable for making selections within one environment, but comparisons between herds based on minimum standards of performance can be undesirable and misleading due to environmental differences, especially if the measures of traits are not well defined.

TRAITS TO CONSIDER OTHER THAN PERFORMANCE

The traits we would like to change in our livestock are numerous, ranging from high yields or rapid growth rate to elimination of horns. In general, we like to allocate priorities for selection as highest for those traits that will increase the out turn of end product desired (production traits). Second priority emphasis should be concerned with reduction in the frequency of occurrence of the traits that inhibit maximizing performance—e.g., traits that lessen fitness. Third priority should go to changes in those traits that will make the animals more attractive to owners or other potential users—e.g., color or body conformation. The order of priority can not be rigid, however, it must vary to some extent with species and desired end product. The traits associated with performance are discussed in subsequent sections by species. Those related to a very important aspect of fitness—reproductive performance—are covered in Chapter 12. The sections that follow are concerned with other aspects of fitness, abnormalities, and resistance to disease.

Abnormalities

Abnormalities inherent in the animal rate a high priority when reduction of frequency of occurrence determines whether the species will survive in a given environment. More than 90 abnormalities have been described for cattle, sheep, swine, horses, and poultry (Stormont, 1961). Those of genetic origin are amenable to control if the "carriers" can be detected. Detection of the carriers is straightforward in the case of the dominant abnormalities, such as achondroplasia in cattle and lethal grey in sheep.

The majority of congenital disorders for which some proof of inheritance is established are due to a single autosomal recessive gene with no visible effect on the heterozygous individual. Some of the more common lethals or semilethals in the homozygous state are mulefoot and muscle contracture in swine and cattle, semihairlessness and leglessness in pigs, and short spines in cattle. The one receiving principle attention among beef cattle breeders in recent decades is dwarfism, although individuals with this condition appear in all species. Among abnormalities of a semilethal nature are muscular hypertrophy, often referred to as "double muscling," which occurs rather frequently in Charolais cattle and cancer eye in Hereford cattle

FIGURE 9 2
A Hereford showing a serious case of ocular carcinoma (cancer eye), a malignant neoplastic growth involving the eye and orbital region. (Courtesy J. C. Bonsma, University Pretoria).

(Figure 9.2). With proper precautions, animals with these conditions may be maintained and used effectively; however, susceptibility to cancer eye resulting from low level of pigmentation of the eyelids, would be undesirable where the likeliness of solar radiation is high. The heritability for eyelid pigmentation is relatively high (.60–.80), consequently, it would not be too difficult to eliminate the condition from the population or at least keep it under control. Double muscling in Charolais cattle is preferred in certain areas of Europe, but because the condition impairs movement and worsens with age it would not be desirable where cattle are expected to exist by grazing.

Some abnormalities, such as dwarfism or mulefoot in cattle, appear to interact with certain other physiological functions to reduce the animal's overall resistance [illegible] group [illegible]ess. These are examples of complete penetration since th[illegible]environment, [illegible] change phenotypic characteristics but affect fu[illegible] standards of performa[illegible] processes. Susceptibility to bloat and [illegible]ing due to environmental differe[illegible] being of genetic origin. If so, th[illegible] of traits are not well defined. [illegible] penetration since the

Resistance to Disease and Insects

Although there is considerable tradition attached to the question of inherited resistance to various diseases and insects, there is only limited information suggesting that breed, strain, or individual genetic differences exist Genetic measures to control diseases in farm livestock have been employed in the past, although they have not been recognized as such The traditional method for eradicating tuberculosis has involved testing and slaughter of infected animals Working on the assumption that animals that do not react to the test are resistant to the disease, breeders have allowed the non-reactors to contribute the preponderance of animals to the subsequent generations This has led to eradication of tuberculosis in a number of areas through what might be considered selective breeding of resistant stock Attempts have been made to eradicate brucellosis through slaughter of infected animals, but this has met with very limited success

Selection for genetic resistance to disease has received most attention in poultry It has been demonstrated that resistance to pullorum and marek's disease can be increased by selection Strains of White Leghorns with high resistance to these diseases have been developed (Hutt, 1964) There is also some evidence of certain breeds or strains of poultry being resistant to ten or more other diseases

Studies by Lush (1950) and Young *et al* (1960) have suggested that the heritability for resistance to mastitis is of similar magnitude as the heritability for milk yield in European breeds of dairy cattle However, we do not understand enough about the disease to construct a good index for ranking animals In the study by Young *et al* , the low genetic correlation between clinical mastitis and bacterial infection (0 23 to 0 29) indicates that selection for either of these would have little effect on the other The high genetic correlation between leucocyte count and each of the other indicators of mastitis (0 80 or higher) suggests that level of leucocytes may be an effective criterion On the other hand, leucocytes are one of the most important defense mechanisms of the body, so if we select cows with low leucocyte counts, we might end up selecting the most susceptible instead of the most resistant cows

In the wet tropics of southeast Asia and Latin America, European type cattle frequently develop foot rot with infectious sole erosion while Zebu cattle remain largely unaffected The first generation crosses between European and Zebu do not seem susceptible, but the disease becomes a major problem with animals of 3/4 or more European blood, implying a genetic relationship Observations from areas

of Latin America suggest a similar variation among breed groups in infection by vesicular stomatitis, which affects the mucosa of the mouth and skin of the feet.

Groups of animals that have had a long exposure to attack by certain organisms have probably evolved some resistance to them, whereas groups not previously exposed have not. Studies with five strains of Australian Merino sheep, one of which was developed in an area of low rainfall, showed that the low rainfall group was markedly more susceptible to fleece rot than the strains from areas of medium-to-high rainfall when placed in a high rainfall area (Dunlop and Hayman, 1958).

There are many other diseases caused by pathogenic organisms for which there is little evidence of genetic resistance. Such a disease is hog cholera. Still others, like aftosa, have supporters as being more prevalent among European type cattle than among Zebus, but this hypothesis is based largely on observations of newly introduced animals. At present, the general consensus is that even though there is some evidence for genetic resistance to pathogenic diseases, little is known about the genetic mechanisms influencing them.

Some examples of protozoa diseases for which genetic immunity has been claimed are tick fever, heartwater, African trypanosomiasis, anaplasmosis, piroplasmosis, and East Coast fever in cattle. N'Dama cattle and West African Shorthorns are said to have a high degree of tolerance to trypanosome infestations, based on the observation that these breeds survive in tsetse areas where other cattle succumb; but no evidence has shown that the tolerance is genetic. Another example of possible uniqueness in resistance comes from the studies by Botero *et al.* (1969), who showed that the Blanco Orejinegro breed of Criollo had lower infestations of *Dermatobia hominis*, the parent of the notorious and destructive *Torsalo* grub, than three other Criollo breeds or Zebu. Preliminary evidence from Australia shows evidence of genetic differences among groups of European breeds of cattle in tick resistance.

Stobbs (1966) introduced heifers of the Boran breed that had been artificially immunized from Kenya into an East Coast fever endemic area of East Africa. These heifers were 57% heavier at 12 months of age than native East African Zebu contemporaries and they were 46% larger at 3 years of age. From this evidence that artificially immunized heifers grew more rapidly when exposed to East Coast fever, he estimated that the heritability for East Coast fever must be near zero.

Instead of genetic resistance to disease per se, there may be traits

with genetic association that directly influence resistance to diseases transmitted by vectors as well as to the syndrome to stress of a tropical environment. Observations made in this field point to the fact that Zebu and Criollo cattle suffer less from ticks than European type cattle. Among the reasons advanced are shorter hair coat, greater number of hair follicles per unit of body surface area, thicker skin, denser epithelial layer, greater depth of hair follicle, and perhaps peculiar secretions from the sebaceous glands exudated through the skin which acts as a repellent. At present it appears that more attention should be directed to selection for anatomical traits that may aid resistance to protozoa diseases, such as those indicated in Chapter 5, rather than to genetic factors that remain too poorly defined to be incorporated directly into a selection index.

Although Hutt (1958), among others, has advocated a strong need for livestock breeders to follow in the footsteps of plant breeders in selecting strains for genetic resistance to disease, most of the evidence currently available does not predict a very promising future for disease control through genetic means. Most animals have a general resistance to one or more pathogenic organisms, but until research provides a better understanding of diseases and their relation to other economically important traits, more precise means of classifying animals as to resistance, and satisfactory identification methods that can be used early in life, selection for resistance does not merit high priority. Furthermore, a system of selection for disease resistance would probably be expensive and there is no assurance that changes in disease organisms would not be greater or more rapid than the genetic progress that can be made in farm livestock. This does not mean that it is not worthwhile to exploit tolerance to disease by induced immunity. This point is discussed in Chapter 13.

MATING SYSTEMS

When the mating of individuals is made without regard to similarity of pedigree or similarity of performance (phenotype), the system is described as random mating. This occurs where there is no control exercised but the mating systems employed by livestock breeders center around attempts to produce changes in the frequency of the genes in a herd or population either in increasing homozygosity, through mating individuals which are alike because of pedigree or phenotypic similarity. Or conversely, mating individuals which are unlike, either from pedigree or phenotypic standpoint to increase

heterozygosity. These two systems are typically referred to as inbreeding and outbreeding, respectively. Within the two, other gradations are often identified, such as linebreeding, outcrossing, crossbreeding, and grading up.

Inbreeding

Inbreeding is the mating of individuals that are more closely related than the average of the breed or population while linebreeding is a milder form of inbreeding. Inbreeding normally has some adverse effects on most performance traits or results in reduction in general vigor. Linebreeding may also reduce vigor but if the animal to which a herd or flock is being linebred is one of truly outstanding merit, the increase in performance from intensifying the genes of an outstanding individual may more than offset any decline in performance due to inbreeding. Because of the probability of a decline in vigor and the high degree of selection required to make this method effective, inbreeding should be employed only in herds of outstanding genetic merit.

Outbreeding

Outbreeding is the mating of individuals that are less closely related than the average of the breed or population. Several gradations are used depending on the extent of the parental relationships as discussed below.

Outcrossing

Outcrossing is the mating system in which the male and female come from the same breed or strain but are unrelated, at least in the immediate parents and grandparents. Outcrossing combined with selection is a useful procedure for intrabreed improvement for moderately to highly hereditary characters. However, the mating of selected animals in outcrosses results in a few undesirable genes being fixed in homozygous form. The practice of continually selecting the best available, but unrelated, males for use is an outcrossing system. Growth rate in beef production is an example of a trait with a rather high heritability for which outcrossing should be effective. Of course, the selection differential among the parents will markedly influence the rate of progress.

Crossbreeding

Crossbreeding is a form of outbreeding that generally refers to the intermating of animals from different established breeds. This system of mating is used mainly to (1) obtain heterosis or hybrid vigor for traits of economic importance, (2) serve as an initial step in grading up or changing a population, or (3) serve as a basis for development of a new strain. Inter-breed matings have also been used as the most rapid means to shift the type of animal to meet fluctuating market demands, to test for possible weaknesses in pure stocks, and to change some characteristics that do not respond very well to selection.

Crossing of breeds to obtain the benefits of heterosis is currently employed quite extensively in commercial production of livestock. The heterosis obtained by crossing is defined as the superiority of hybrids or crosses over the average of the parental types or over either parental type. The genetic reason for heterosis is not entirely understood, but the proposed hypotheses for the genetic bases are dominance, overdominance, and epistasis. The effects of favorable genes are generally dominant to those of unfavorable genes. When lines, breeds, or species with different gene frequencies are crossed, the resulting offspring will be more heterozygous than their parents and the dominant favorable genes will mask the unfavorable recessives. If this occurs, the performance of the hybrid will surpass that of the parents—even the better parent—if both favorable and unfavorable genes were present in each parental line. In other words, each parental line or breed will be homozygous for some loci, for favorable genes at some and for unfavorable genes at others. If the first parental breed complements the second, the hybrid or cross will have favorable genes at more loci than either parent. Consequently, when favorable genes are dominant, the performance of the hybrid will be superior to that of either parental line.

The second explanation, or partial explanation, for heterosis involves epistasis or interallelic interactions. This possible basis of heterosis would occur if the combination of heterozygotes resulted in an interaction such that a phenotype larger or in other ways more desirable than would be expected from average phenotypes would result.

The third hypothesis explains heterosis by the so-called overdominance theory. This theory suggests that the heterozygote is superior to either the homozygous dominant or the homozygous recessive individuals.

At present, the best hypothesis for heterosis from crossing is that all of the foregoing possibilities may be involved. But a full under-

standing of the genetic basis of heterosis requires further knowledge of the physiology of gene action and the physiological reactions resulting in heterosis.

Grading Up

Generally this system of mating involves the practice of breeding purebred sires of a given breed to low quality or "nondescript" females continuously for several generations. The concept may be applied too for the use of high quality sires within a given breed. It usually refers, however, to the use of introduced breeds, primarily European types, to change the characteristics of local types.

A resume of the results of the foregoing systems of mating and their possible applications to situations in the N-S 30° latitudes is given in Chapter 10.

SELECTION OF LIVESTOCK

Whatever the system of mating employed by the livestock breeders, selection is the key to success. The questions are: What should the goals be? And how may they best be achieved within the resources available or those which can reasonably be made available. These questions are discussed below by species.

Dairy Cattle

In a dairy enterprise, the sale of milk is normally the primary goal, although the returns from beef, breeding stock or bullocks for agricultural power may make a significant contribution. A number of factors other than milk yield may affect the economic returns, from dairying —among them, the fat content of the milk.

The major opportunity for selection to improve dairy production in most tropical areas will probably be offered by institutional farms maintained to supply seed stock or commercial enterprises engaged in systematic production of milk. These are the herds where environmental conditions are most likely to approach the level required for identifying possible genetic variation among individuals or groups. Optimal environments are necessary because, even in well managed herds, the expected genetic change per year for most traits is meager.

In some countries a single breed type is widely distributed, but *in most, the cattle are of three types: (1) high grades of European* breeds, (2) intermediate breeds produced as direct crosses between European and indigenous breeds, and (3) indigenous stocks. A number of good texts, such as Rice *et al.*, 1967, deal extensively with expected progress in selective breeding in European breeds. The ensuing discussion will be concerned principally with current evidence on the prospects of improving indigenous stocks, although some values for European breeds in temperate zones are included for comparative purposes.

In Table 9.1 are some representative repeatability and heritability estimates for characteristics of European dairy breeds in temperate zone areas. It is evident from the values that most rapid genetic change could be expected through selection for fat content. Changes in protein content could also be brought about fairly rapidly. But changes in milk yield and other traits in the 20–40% range would be slower, and little gain could be expected for traits associated with reproduction and tolerance to hyperthermia conditions. Most of the

TABLE 9 1
Some representative repeatabilities and range of heritability estimates for characteristics of European dairy breeds in temperate zone areas

Characteristic	*Repeatability*	*Heritability (%)*	*Genetic correlation with milk yield*
Milk yield	35 to 60	20 to 30	
Fat (%)	70	50 to 60	− 20 to − 50
Protein (%)	42	45 to 55	− 20 to − 45
Fat yield	49	20 to 30	85 to 95
Total solids yield	47	20 to 30	85 to 95
Feed efficiency	60	30 to 40	50 to 60
Mastitis	31	10 to 30	?
Mature size		30 to 50	− 20 to + 10
Milking time	52	30 to 40	?
Type score	.48	15 to 30	00 to .20
Reproductive efficiency	04	0 to 10	?
Services per conception	.00 to 22		
Calving interval	07 to .13	0 to 5	
Days 1st service to conception	.11	7	
Days open		9	
Response to standard heat-tolerance test	.17 to .20	−1 to +15	− 03
Rate of milking	.58	54	.49

estimates in Table 9.1 include multi-herd samples and sizable numbers of animals.

By contrast, the estimates for some similar characteristics of indigenous stocks involve single herds and rather small numbers of animals; and, with one exception, all herds were maintained at government stations. Nevertheless, most of the repeatability and heritability values for the indigenous stocks fall within the same ranges as those for European breeds (Table 9.2). The indigenous stocks were subdivided into "selected" and "random" groups. The "selected" group represented herds that had been established long enough—for two or more generations—to have been produced from the foundation stock. The "random" group represented herds that had been in existence for fewer years; but during this period they

TABLE 9 2
Phenotypic and genetic parameters (within herd) for "selected" and "random" bred cattle of tropical origin

Characteristic	*Repeatability*	*Heritability* (%)	*Est. genetic[a] gain/yr* (%)
	SELECTED[b]		
Lactation milk yield	.41 to 65	16 to 28	30 to 74
Lactation length	.42 to 46	−13 to +10	00 to .60
Calving interval	07 to 42	0 to 88	00 to 07
Age at first calving	00 to 37	0 to 39	00 to .15
Length of dry period	00 to .11	− 1 to + 4	
Milk-fat percentage	.32 to 64	22 to 34	
Birth weight	43 to 72	− 1 to +17	
6-month weight	41 to 76	− 1 to +13	
2-year weight	34 to 88	18 to 27	
	RANDOM[c]		
Lactation milk yield	32 to 76	20 to 64	00 to .15
Lactation length	05 to 51	5 to 42	00 to 03
Calving interval	14 to 67	−10 to +30	
Length of dry period	10 to 24	−53 to +15	
Age at first calving		8 to 25	
Birth weight		17 to 33	

[a]Estimated gain per generation generation interval
[b]Includes 7 breeds in 6 countries (Kenana and Butana, Sudan Criollo Costa Rica and Venezuela Gir, Brazil Tharparkar Gir Sahiwal and Red Sindhi India and Philippines)
[c]Includes 11 breed groups in 7 countries (Malvi, Malawi Hariana, and Deshi, India, Nguni, Nganda, and East African Zebu Uganda Baladi and Damietta, Egypt Sinhala, Ceylon Harro Ethiopia, and Blanco Orejinegro, Colombia)

were expanding, hence, little or no culling or attention was given to selection of sires beyond their phenotypic characteristics The selected group included one or more herds of seven recognized breeds in six countries, while the random group consisted of 11 breeds in seven countries, largely single herds per breed For these reasons, the heritability estimates are somewhat more variable in the random group—e g , −53% for length of dry period as compared to near zero in the selected group Another basis for the subdivisions is the characteristic coefficients of variation The coefficient of variation for milk yield in the selected group is only slightly higher (23–38%) than for European breeds (15% on a within herd and year basis, or 18–20% on an intra-herd basis) as compared to 38–149% for the random group

The magnitude of the coefficient of variation in the indigenous groups indicates an opportunity for selection The distribution of yields shown in Figures 8 12–8 15 portrays the extent of the variability for milk yield in four breed groups Even though the potential may exist, the progress that can be realized by selective breeding in the indigenous stocks hinges on numerous factors These include the numbers of animals available, the fluctuations in the environmental conditions, the relationship of milk yield to other important traits, and the accuracy of systems for identification of superior genotypes

Milk Yield

The milk yield per cow per year with an acceptable composition and the length of the cow's productive life are the primary factors for economical dairy production These are influenced to varying degrees by feed supplies, length of lactation, frequency of milking, age of first calving, calving interval, body conformation, body size, milk letdown, fertility, longevity, feed efficiency, resistance to disease, and docility Since the average milk yields are very low in the majority of the indigenous groups, as measured by temperate zone standards, it seems that milk yield should be given first priority in selection, and other factors considered only as they relate to milk yield Fortunately, most of the factors have a direct relationship to total milk yield (Table 9 1) At least this is the case in European breeds and there is no reason at this point to expect dissimilar relationships in the indigenous types The fat, protein, and total solids contents of the milk of tropical breeds are all at least one percent higher than for several European breeds (e g , fat percent 4 to 5+%) More total fat and protein may be expected from increased yield than from direct selection for these components So it would seem that for the predictable future little

emphasis should be given to increasing fat or protein percentages—especially since they have negative relationships to milk yield. It may be that in selecting dams of sires, cows with milk below 4.0% fat and 3.0% protein should be excluded.

Lactation Length

Lactation length has a fairly high correlation with lactation yield in all groups (Holsteins 0.50, selected indigenous cattle 0.42 to 0.60, and random indigenous cattle 0.44 to 0.67). As stated in Chapter 8, the average length of lactation in many groups of indigenous cattle is 50 to 100 days shorter than for European breeds. There is evidence of some genetic influences but heritability is low at least in the selected group (Table 9.2). If this is true, selection for increased milk yield will give appropriate emphasis to extending lactation length.

Age of Calving

Age of first calving of indigenous groups averages from 4 to 33 months later than for European breeds. Environmental effects are important, but genetic influences may also be involved, as illustrated in Table 9.3. The difference between the average age of first observed estrus for Jerseys and Red Sindhi-Jersey crosses in Beltsville, Maryland (temperate) and the age for similar cattle in Jeanerette, Louisiana (subtropical) was large, indicating some environmental effects, however, the later onset of estrus in crosses with 1/4 Jersey at both locations and pure Red Sindhi at Jeanerette suggest a genetic relation between breed and age of first estrus. A series of experiments in India with the Red Sindhi, Tharparkar, and Sahiwal breeds, on medium and high levels of nutrition, showed that the average age of first estrus could be reduced from 26 to 21 months by level of feeding. Even

TABLE 9.3
Average age in days of first estrus in Jerseys and Red Sindhi-Jersey crosses at two locations

Herd	*Jersey*	*3/4 J*	*1/2 J*	*1/4 J*	*Red Sindhi*
Beltsville	404 ± 2.9	397 ± 5.5	418 ± 5.3	444 ± 7.9	—
Jeanerette	497 ± 12.6	497 ± 26.8	485 ± 9.6	533 ± 21.9	790 ± 3.7

Source: Adapted from McDowell *et al.* 1959

though some emphasis should perhaps be given to selection for earlier age of first calving, it appears that the average age for indigenous groups could be reduced at least 12 months through shifts in management regimes

Calving Interval

Variations in calving interval among tropical cattle seem to have some genetic basis, as shown by the statistics for Blanco Orejinegro cattle, from Colombia, (372 days) and Harro cattle from Ethiopia (366 days) versus those for other groups from India and elsewhere (422–526 days) But as in the case of age of first estrus, environmental influences appear to be the major causes of long calving intervals The generally low heritability estimates further support the hypothesis that little change could be expected by selecting for shorter calving interval on an intra-breed basis

The fertility level, measured as services per conception, is about the same for native and European breeds in their respective home environments (1 6–2 0) The repeatability for services per conception is low in European breeds (Table 9 1) indicating that environmental influences are much greater than genetic

Body Conformation

A number of breeders in the U S and elsewhere have given substantial emphasis to body conformation or type characteristics of both males and females Some breeders who sell a large portion of their stock for breeding give 3 to 5 times as much emphasis to type as to milk yield in their selections, whereas, in commercial herds the emphasis is reversed Although breeds indigenous to the tropics would not rate high in the show ring by U S standards, they have few problems with bad feet and legs or udder attachments that break down to the point that they affect length of productive life There is some evidence that if machine milking were practiced, problems could arise with Zebu type cattle, however

Branton *et al* (1966) reported that crosses between Red Sindhi and Jersey with ¼ or less Jersey developed such large front teats at older ages that they were unsuitable for machine milking When the same types of cows served as nurse cows to rear calves, calf losses were abnormally high because the very young calves were unable to nurse the exceptionally large front teats Similar experiences have

occurred in Brazil with Gir cattle (a Zebu type) when used in commercial dairy herds. No studies have been made on the heritability of teat size in tropical breeds. Teat size is of no serious concern under hand milking systems but it could be a limiting factor in the utility of some cattle if machine milking is expected.

Body Size

As pointed out in Chapter 8, the range in mature body size among tropical breeds is large. In general, the Sahiwal breed of India is one of the largest breeds and is rated among the best milk producers, but up to now little attention has been given to the association of size and performance on a within breed basis. When selections are made for increased milk yield, the average mature weight of the breed will probably increase to some extent. Based on data from European breeds, it would not be desirable to simultaneously select for body size. The rise in milk yield per 50 kg increase in body weight for cows of the same age is only about 100 kg (McDaniel and Legates, 1965). When the costs of maintaining the extra body weight are taken into account, the additional 100 kg of milk will not usually offset the costs. Some breeders in temperate areas hold the view that larger cows possess more stamina and have longer productive life, but this has not been proven in either European or tropical breeds. Animal size should be given emphasis only if it is accompanied by increased yields of a ratio of greater than 2:1.

Milk Let-down

Rate of milk let-down is a serious problem not only in the utility of tropical breeds for commercial dairying but also in the assessment of dairy merit. For a large number of cattle, suckling by the calf is the only stimulus that produces a response (Mahadevan, 1966). However, suckling may not actually be required, it is common practice for herd owners of India and Venezuela to tie the calf near the head of the cow before milking, without letting the calf touch the udder until most of the milk has been removed. It is not clear whether the presence of the calf is sufficient stimulus or if the massaging of the udder by the calf to start the milk flow is necessary for the release of oxytocin from the maternal neurohypophysis.

The maternal instinct or attachment to the calf in tropical breeds is greater than in most European breeds. It may be that the traditional

practice of having the calf present serves more to reduce nervous tension in the cow caused by the presence of the milker than to stimulate milk let-down In a herd of Harro cattle in Ethiopia, nearly 50% of the cows either refused to let a milker near or yielded little milk when the calf was not present Branton *et al* (1966) found that 38% of first generation Jersey-Brahman crosses lacked the dairy temperament to adjust to a milking parlor routine An additional 26% had lactations of less than 150 days due to poor temperament The undesirable temperament seemed to be highly repeatable and heritable

It is clear that when attempts are made to identify superior females, some system must be devised to standardize the quantity of milk taken by the calf, either by merely having the calf present or letting it suckle for a standard length of time The other approach would be to avoid the use of the calf at all Initially, the average production of the herd would probably decline, but the development of several herds of cattle that let down their milk without a calf present—e g , the Sahiwal herd at Pousa, India and several herds of Gir cattle in São Paulo state, Brazil—indicates that early separation of the calf should be one of the environmental standardizations imposed at the outset of the selection scheme It may be difficult to change practices on older cows It is recommended that milking without calf be initiated with first calving If this is done, these cows must be milked separately from old cows, or the change will not be effective Since the tendency for poor dairy temperament is closely associated with lactation length and low yields, selection for milk yield should improve dairy temperament

Persistency

Frequently indigenous cattle show poor persistency of milk yield which results in short lactations and low total yields Some genetic association has been indicated by progressive changes in crossbreds For example, first lactation persistency of milk yield was inversely related to the proportion of Zebu heredity in Red Sindhi-Jersey crosses (Table 9 4) The Jerseys and ¾ J crosses were significantly ($P < 0.05$) higher in persistency than the ¼ J crosses The ranking of the breed groups for persistency was the same as the ranking for milk yield, which means that selection for total lactation milk yield would enhance persistency

Saxena and Kumar (1960) also showed, from a study of milk records on a herd of Sahiwals at the Indian Agricultural Research Institute, New Delhi, that low persistency values corresponded to low

TABLE 9.4
First lactation persistency of milk yield for Red Sindhi-Jersey crosses and contemporary Jersey herdmates.

Breed group	No. animals	Mean*
Jersey	75	18.5±7.6
¾ J	26	20.3±18.6
½ J	90	37.1±42.8
¼ J	31	76.2±60.2

Source Adapted from Branton et al., 1966
*Low values indicate high persistency

yields; but there was variation in persistency among poor yielders. The levels of persistency, initial yield, and total lactation yield were positively correlated, with persistency alone accounting for about 60% of the variation in milk yield.

Observations in Australia with crosses of Jersey with either the Sahiwal or Red Sindhi breeds have indicated that level of the assay for the hormone prolactin might be included as a refinement in the overall selection index.

Longevity

In general, reports convey the impression that cattle of tropical breeds remain in herds longer than those of European breeds. This is difficult to discern, however, due to variations in age of first calving and level of performance tolerated before culling as well as differences between static and expanding herds. For tested herds in New York State, the average herd life beyond first calving has been about 3.7 years for some time, with 3.4 lactations per cow. Differences among breeds have not been evident. In Puerto Rico, cattle of predominately Holstein breeding have averaged 4.1 years in the herds but due to long calving intervals have completed only 3.1 lactations. Criollo cattle in Venezuela have averaged 3.6 lactations with total herd life of nearly 5 years.

A study of a large herd of Hariana cattle in India (Ngere, 1970) revealed an average herd life of 4.6 years after first parturition. The cattle averaged 3.1 lactations. In this herd longevity was markedly influenced by the period the cows were in the herd. Cows purchased as foundation stock had an average herd life of 5.1 years and completed 3.6 lactations. After the herd reached a designated size, and culling was initiated, longevity was 3.8 years, with 2.8 lactations completed

per cow. A similar pattern occurred in a herd of Deshi cattle at the Haringhata station.

We can say with certainty that a cow of an indigenous breed will likely last longer in a poor environment than one from a European breed. But given reasonably good levels of management, including feeding and disease control, any advantage for the indigenous cattle is doubtful.

Feed Efficiency

Attainment of the highest possible return over feed costs is the goal of a dairy enterprise. This may be maximized by keeping the cost of feed supplies as low as possible and having cattle that will utilize the feedstuffs most efficiently. Evidence to date from the U.S. indicates that selection for increased feed efficiency for the production of milk would be effective. Because of the high genetic correlation between milk production and efficiency, and because the ratio of the heritabilities of these traits appear to be approximately equal, selection for milk production alone will automatically select for increased feed efficiency (Freeman, 1967). These findings are based on experiments with European breeds on levels of feeding well above those prevailing in the warm climates.

In Table 9.5 are the averages for feed efficiency and milk yields of Jerseys and various crosses between Red Sindhi and Jersey on high and low levels of feeding. On high feeding the gross efficiency—expressed as kg of 4% fat-corrected milk (FCM) produced per therm of estimated net energy (ENE) consumed—decreased with increasing Red Sindhi heredity in crosses. The Jerseys and ³⁄₄ J were significantly higher in feed efficiency than the ½, ¼, or ⅛ J crosses. On low feeding (approximately 80% of recommended allowances), the ½, ¼, and ⅛ J crosses had higher efficiency than Jersey or ¾ J crosses although the differences were not significant.

In Uganda, East African Teso Zebu cattle showed only a 5% increase in lactation milk yield (534 kg to 561 kg) when fed concentrates heavily in addition to grazing as compared to grazing alone. Those receiving concentrates gained considerably more weight than controls.

The findings with the crosses in the U.S. and in Uganda hint that indigenous breeds may not respond to greater food supplies with increased milk yields. It is also evident that the level of feeding that can be provided should be considered in selecting the most suitable genotypes, particularly where feeding is to insure the highest return per cow.

TABLE 9.5
Gross feed efficiency of Jerseys and Red Sindhi-Jersey crosses on high and low levels of feeding for lactation period up to 305 days.

	Breed groups				
	Jersey	*3/4 J*	*1/2 J*	*1/4 J*	*1/8 J*
HIGH FEEDING[a]					
Number of animals	18	11	25	11	7
Feed efficiency[b]	.81	.81	.74	.66	.64
Body weight gain (kg)	49	57	59	39	43
FCM yield/lact (kg)[c]	4,259	4,172	3,169	1,811	1,721
LOW FEEDING[d]					
Number of animals	8	7	8	6	4
Feed efficiency	.36	.37	45	.41	.40
Body weight gain (kg)	−64	−44	−14	22	31
FCM yield/lact (kg)	3,010	2,887	2,524	1,353	1,044

[a] Ration of concentrates, alfalfa hay, and corn silage fed at 125% of Morrison standard (see Chapter 7)
[b] Feed efficiency = kg of 4% fat corrected milk produced per therm of estimated net energy consumed.
[c] FCM = 4% fat corrected milk.
[d] Ration same as [a] fed at 80% of Morrison standard

In summary, it is apparent that the level of fat and other milk constituents is satisfactory in most tropical breeds. The animals' body conformation is such that their herd life expectancy is as good as that of European breeds—or even slightly better. On the other hand, length of lactation, age of first calving, calving interval, rate of milk let-down, persistency, docility, and level of milk yield all need improvement to make them acceptable for commercial dairying. Although there is some indication of small genetic influences for age of first calving and calving interval, both can be lessened significantly through management. Rate of milk let-down, lactation length, persistency, and docility are closely correlated with total lactation yield; therefore selection for milk yield alone will give emphasis to improvement in the other traits. Certainly this will be simpler than attempting to use a complex selection index.

Mahadevan (1966) points out that because of strong maternal instinct toward the calf on the part of cows of most breeds native to the tropics and other factors it will be very difficult to distinguish true differences in the performance among individuals. He contends that the cow that produces only 100–200 kg of milk due to poor temperament should be excluded from estimates of group or individual variation because this is not a real reflection of her genotype. It is

true that if such a cow were left alone to suckle her calf she would yield much more On the other hand, it is more realistic to take the position that selection of superior individuals must be done within well defined parameters to be effective If cows are to be milked by machine without the calf present, selection should be against those animals that do not respond to the environment irrespective of what they might yield under other environmental conditions

If selective breeding is to be made effective in most areas, it is clear that governmental support will be required to provide technical supervision of recording and guidance in making selections, especially in relation to progeny testing of sires The most satisfactory procedure will sometimes be for governments to establish "seed-stock" herds and distribute sires for use with the general population This method has been employed in several countries (e g , Egypt) but the intensity of selection must be stepped up if genetic changes are to be effective

Adjustments for Environmental Influences

Since the lactation yield of individual cows results from the interplay of heredity and environment, estimations of the dairy merit of the females in a herd at a given time should include adjustments for several measurable environmental influences The influences that have been considered in the temperate zone include length of the lactation period, number of milkings per day, age of the cow at parturition, length of the preceding dry period, season of freshening, and days open (time from parturition to conception) Each of these has been studied in one or more herds of tropical breeds Some of the resulting adjustment factors are in agreement with those accepted for European breeds, while others have been varied widely

The values for extension of incomplete records to a standard lactation period of 300 days (Table 9 6) and age adjustment factors for standardizing milk records to an age of 90 months of Hariana cattle (Table 9 7) represent near average values for most tropical breeds (Ngere, 1970) The factors for converting incomplete records are often useful in extending to some standard base, records of cows that may have been terminated following the death of a calf, physical injury, an attack of mastitis, or aftosa The values for U S Holsteins (Table 9 6) are based on massive data, while those for Hariana involve less than 600 cows Differences in numbers are no doubt responsible for the variation in the two sets of data up to 120 days

the percentages of genetic improvement that can be expected in dairy cattle are as follows:

Source	*Percentage of improvement*
Sires of heifers	18
Sires of bulls	43
Dams of bulls	33
Dams of heifers	6

This shows that about 94% of the genetic progress comes from the selection of sires used in the herd and only about 6% from the culling of cows. Therefore, unless records are evaluated to identify dams of bulls, and in the selection of sires to produce the bulls, they will hardly be worth the effort.

Beef Production

Traits to Consider

In many respects selective breeding for beef production is different than for dairy. Although the aim of selection appears simpler, it is complicated by different criteria of excellence, such as variation in type of carcass desired from country to country, and by the fact that the range of environmental conditions under which cattle are kept to produce beef is usually wider than for dairy animals. Accordingly, it is important that those concerned with selective breeding ask themselves what kinds of environmental situations they foresee for the next two decades. No doubt some systems of agricultural production will remain unchanged, whereas in others improvements in management and disease control may be feasible. If it is likely that the present environmental situation will continue, breeders must determine how extreme the genotype environmental interaction is before attempting improvement.

Within a given area, the general aims of selection may be fairly clear. Most of the time, the characteristics of economic importance can be divided into three groups. (1) reproductive performance, (2) growth rate, and (3) carcass characteristics. Frequently, low reproductive performance is the most serious problem, but selective breeding offers little hope for improvement as indicated by the heritability estimates for calving interval in Tables 9.8 and 9.9. Adjustments will come about largely through changes in husbandry practices.

TABLE 9.8
Estimates, for European breeds, of heritability of some economically important traits in beef production

Trait	Approximate range of heritability (%)
Calving interval	0 to 15
Birth weight	35 to 40
Weaning weight	25 to 30
Maternal ability of cow	20 to 40
Summer pasture gain of yearling cattle	25 to 30
18-month weight of pastured cattle	45 to 55
Cancer eye susceptibility	20 to 40
Mature cow weight	50 to 70

Source Adapted from Warwick 1969

TABLE 9.9
Means and approximate average heritability (h^2) for several economically important traits in beef production of "selected" and "random" bred native groups

Trait	Selected[a]		Random[b]	
	Group avg	h^2 (%)	Group avg	h (%)
Age at first calving (months)	46	7	52	14
Calving interval (days)	480	10	542	6
Weaning weight (kg)	137	13 to 35	–	–
Birth weight (kg)[c]	25	47	21	29
Mature weight (kg)[c]	413	40	327	42
Daily gain, birth to sale (kg)	6	28	2	3
Dressing percentage	54	20	48	24
Age at slaughter (years)[d]	3 9	–	4 9	–

[a]Herds in existence for 10 or more years with indication of sire selection
[b]Recently assembled herds or open range with little or no sire selection
[c]Females only
[d]Males only

Growth rate is one of the most important characteristics of beef production, provided it can be achieved without deterioration in other traits, especially reproductive performance. Its heritability, both in European breeds (Table 9.8, weaning weight and 18-month weight of pastured cattle) and in "selected" native groups (Table 9.9, birth weight and mature weight), is such that it should respond easily to selection based primarily on performance testing of sires.

Carcass characteristics are important in the U.S., but will warrant

TABLE 9 6
Factors for converting incomplete milk records.

Lactation interval (days)	Adjustment factors	
	Holsteins, U.S.[a]	Hariana, India[b]
30	7.42	10 40
60	3.74	7.81
90	2 56	5.32
120	1.98	3.99
150	1.64	2.34
180	1.41	1.78
210	1.26	1.38
240	1.14	1.27
270	1.06	1.00
300	1 01	–

Source Holsteins—Dairy-Herd Improvement Association Letter, Vol 41, No 6, USDA, Washington, 1965 Hariana—Ngere, 1970
[a]Cows over 3 years old.
[b]Cows of all ages

TABLE 9.7
Age-adjustment factors for milk yield of Holsteins and Hariana cattle.

Age (months)	Adjustment factors	
	Holstein, U S	Hariana, India
24	1 31	–
30	1.24	–
36	1.10	–
42	1.12	1 17
48	1.08	1.12
54	1 04	1 13
60	1 02	1 11
66	1.02	1.08
72	1 00	1.06
78	1 00	1.04
84	1 00	1.03
90	1.01	1.00

Source See Table 9 6.

Most estimates of changes in lactation yields with increasing age after first calving in tropical breeds have used the ratios between lactations without regard to age of calving. The estimates for changes in yield from first to fourth or fifth calving have varied from near zero up

to 38%. Instead, Ngere considered changes in yield with age irrespective of lactation number. On this basis the estimates needed to adjust for age differences are similar to those for Holsteins in the U.S. (Table 9.7).

Although it is standard practice to milk nearly all cows twice a day, some are milked three times daily. Numerous studies on European breeds indicate that on the average a cow milked three times daily will produce 15–20% more milk than if she is milked twice a day with younger cows showing a greater increase in production from more frequent milking than older cows. Studies with tropical breeds provide similar values. Four year old cows (first lactation) produced 17% more on a three times daily milking schedule, while older cows produced only 15% more (Mahadevan, 1966 and Ngere, 1970).

Pearson *et al.* (1968) observed seasonal differences of 11% in lactation yield of local cattle in Colombia between cows calving in the most favorable month and those calving in the least favorable month. The cows that started lactation during the period of heaviest rains—October to November—had the lowest yields. Similar seasonal affects have been reported for Hariana cattle in India, but the lowest yields were for cows calving late in the monsoon season—August to November (Kohli and Suri, 1960). Although the lowest yielding Hariana cows calved during the season of favorable feed supplies, they were subjected to seasons of poorest feeding for most of their lactation. Still, many other studies on tropical breeds point up variations in lactation yields due to season of calving ranging from 0 to 50%. In general, the magnitude of the variation is directly related to availability of feeding. Most studies from the temperate zone show 10–14% variation in yield with two distinct seasons. Cows calving from April–October have the lowest yields. Since seasonal effects may be large and as a consequence seriously bias selections, some estimate of the variation should be attempted as soon as recorded data are available.

Days dry prior to parturition do not greatly influence lactation yield in tropical cattle and neither does pregnancy. In Holsteins, days open accounted for 4–7% of the variance in 305-day records (Smith and Legates, 1962) but thus far the variance has been less than 2% for tropical breeds. Since the calving intervals generally equal or exceed 400 days and lactation length is less than 300 days, an adjustment in the lactation yield for days open would probably not be required.

It should be kept in mind that the main purposes of keeping records in a dairy enterprise are to serve as an aid in culling of females and, more important, to provide a basis for progeny testing for selection of sires. According to the work of Robertson and Rendel (1950),

feed resources. If a seedstock herd is established to distribute a large breed, such as Charolais, for grading up local stock, the first generation crosses may perform in an acceptable fashion but later crosses with 75% or more Charolais breeding may produce an animal with maintenance needs higher than available feed supplies. Poor nutrition will then be a serious deterrent to the utility of the new group. If seedstock herds are to be of value, breeds employed and emphasis in selection must be for traits that are compatible with maximum productivity in the herds to which they directly or indirectly supply breeding stock.

In operations outside the seedstock herds progress will depend upon how conscientious the operators are about castration of male calves so that only improved sires will be the breeders of the herds. In most places scales for weighing will not be available. At best, record keeping will consist of notations of calves born, losses of calves and cows, and the approximate age of sale for slaughter. However, where motor transportation is available, governmental agencies may provide weighing services once or twice per year.

In some areas it is possible that for beef production we shall see a breeding system not far removed from that in broiler chickens, in which heterosis is used to increase the calf crop and the first generation crossbred females are then mated to a certain sire line to produce animals for sale. In other areas, new strains will emerge from crossbred foundations. For both systems, seedstock herds will be quite helpful. These systems of mating are discussed further in Chapter 10.

Sheep

Traits to Consider

The type of sheep production likely to be most suitable depends upon the social and economic development of the area. Sheep are most often kept in tropical areas of 50 cm annual precipitation or less. The type of sheep maintained depends upon the value the human population assigns them.

There are very few estimates of repeatability or heritability for breeds of sheep indigenous to the tropics, except for the Merino in the tropical area of Australia. Data from the temperate zones must, therefore, represent the principal source for guidelines on expected progress from selection in the tropics. From the estimates of repeatability and heritability in Table 9.10, it is evident that genetic changes are reasonably easy to obtain for wool characteristics and number of lambs born.

less attention in most tropical areas for a long while unless carcass characteristics are closely associated with growth rate. It is conceivable that selection for growth rate alone may produce a rather leggy animal, although not necessarily an animal whose yield of useful meat is less than for one with traditional conformation.

In Table 9.8 are estimates of heritability for some economically important traits in beef production for European breeds. Those for "selected" native groups (Table 9.9) are in general agreement. As might be expected, the estimates for the "random" native groups are generally low due possibly to poorer environmental conditions and to little or no attention given to sire selection. The heritabilities indicate that most characteristics could be changed through selective breeding.

There is likely some negative relationship between growth rate and ability to fatten at an early age. For example, the Holstein breed ranks among the highest in growth rate but it will not fatten as readily as many breeds until it has reached 500 kg or more. Since carcasses with little fat are typically preferred in the tropics, the negative relation should not be too serious. There is a rather high positive genetic relationship between rate of gain and efficiency of gain, when efficiency of gain is expressed as gain per unit of feed consumed and final body weight is 500 kg or less. It appears that the genetic relationship between rate and efficiency of gain is high enough in most groups to make selecting for rate of gain a reasonable means of selecting for efficiency of gain. There is some tenuity for the relation of rate of gain and efficiency of gain since the preponderance of the evidence comes from drylot feeding. Even though the information available on cattle grazed throughout their lifetime is restricted; it seems that the rapid gainers on grass are also the more efficient. This seems to hold when performance is judged on age to attain a given final weight.

A measure of weight at some given age, such as 12, 18, or 24 months, is more highly heritable and meaningful than gain in any part of the period (Warwick, 1969). Touchberry (1967) found that mass selection for weight at one year of age in N'Dama cattle of Sierra Leone would result in an approximate 6 kg increase per generation, with the expected genetic gain for weight at other ages not appreciably different.

The possibility that selecting for gain under drylot feeding might not provide cattle best adapted to pasture conditions makes it inadvisable to test under drylot feeding if the objective is performance on grazing. Heifers that are to serve as herd replacements should always be tested on the type of feeding regime they will experience in later years. Since individual feeding cannot be practiced under such condi-

tions, mass selection will of necessity be the primary means of genetic improvement.

In several respects selection for beef production is simple because many factors of economic importance, such as growth rate, can be observed in both males and females, and traits under selection can be observed at a relatively young age. Also for certain characteristics, such as carcass quality, the external appearance of the live animal is a better indication of the animal's value than it is in dairy production. A disadvantage in beef production, which may limit progress is the fact there is no one best measure of the end product comparable to the lactation milk record in dairy production.

Implementing Improvement Programs

Several important problems arise in developing programs towards selective improvement for beef production in tropical areas. Providing the necessary records to judge performance will require vast changes of existing systems of management on farms. Even if records are kept, there is the question of their suitability for making useful decisions because of the strong influences of the environmental conditions.

In the past it has been fairly common practice in a number of countries in the N-S 30° latitudes for governmental agencies to support seedstock herds for the purpose of providing sires for general distribution. The desirability of this practice depends upon whether the quality of the sires produced is better than the average for the general population and whether they are suitable for a farm environment. Certainly, the value of such a system could be challenged in some areas. Distribution of sires from governmental herds has probably best served to provide sires for changing the local breed, as for example in Venezuela, where the Ministry of Agriculture has maintained herds of Zebu, to produce bulls for grading up the local Criollo types to Zebu.

Some of the purported seedstock herds are not capable of contributing the needed characteristics since emphasis is frequently given to color pattern or certain traits associated with body conformation that have little or no relation to economic value. There is also the question of what environment should be provided for seedstock herds. If the level of feeding in the seedstock herd is much higher than that available elsewhere, the recognition of the characters essential for fitness in the outside environment may be overlooked. Also the inherent size of the breed group in the seedstock herd must be one whose maintenance requirements do not equal or exceed the

improvement in the tropics ought to involve a selection index that incorporates milk yield, reproduction rate, meat production, and wool. This point is examined further in Chapters 10 and 15, especially the latter.

Implementing Improvement Programs

Due to the traditional husbandry systems often practiced in tropical and subtropical areas the wisest policy for improvement would be to carry out selective breeding in seedstock flocks. As recommended for beef production, these flocks could in turn serve as a reservoir of stocks for upgrading the local populations. But the environment for the seedstocks must be carefully considered if the results are to be applied in practice. Flock owners may refuse to accept rams produced at a government experiment station unless they have reasonable confidence the rams offered to them will contribute to their flocks (see Chapter 15).

In the seedstock flocks emphasis should be given to prolificacy of ewes—that is, regular lambing and, possibly, frequency of twinning. Most tropical breeds appear to have reasonably good lambing rates already. Emphasis on twinning should depend upon the level of environment; twin lambs may be a disadvantage where feed supplies are poor, but in general twin production is most profitable.

Birth weight is frequently of no real value in estimating later performance. It has been found in Egypt that the growth rate of Rahmani sheep up to one year of age was much higher than for Ausimi sheep even though there was no difference between breeds for birth weight or weaning weight at 17 weeks of age (Ghoneim *et al.*, 1959). Nevertheless, birth weight is generally related to viability and rate of growth. Tropical breeds are sometimes low in viability due to size of lamb at birth. Normally the birth weight of single lambs in tropical breeds is 1 kg less than for temperate breeds.

Seasonal breeding is a serious limitation in numerous temperate zone breeds but less important in tropical breeds. Nonetheless, emphasis should be given to selection for ewes that breed over the longest period.

Since weaning weight of the lamb is an expression of maternal ability as well as the growth potential of the lamb, recordings should be made. Coupled with this should be some recordings of actual milk production by the ewes during lactation. It has been suggested that milk yields at 40 and 80 days will be satisfactory indices to characterize the ewe's milk yield (Haring, 1965).

TABLE 9 11
Changes in selection differential among ram lambs for growth rate and staple length within a large flock of sheep in Colorado from 1960 to 1966

Year and category	Lambs born (no)	Weaning weight (kg)	Staple length (cm)
1960			
Total ram lambs	577	33 9	4 17
Ram lambs saved	274	38 8	4 42
Ram lambs culled	303	29 5	3 96
1966			
Total ram lambs	563	39 4	5 08
Ram lambs saved	240	42 9	5 28
Ram lambs culled	323	37 3	4 95

The emphasis on fleece weight and quality will depend upon the use of the wool Where wool is for the production of locally used products, it may be undesirable to give much emphasis to selection for medium or fine wool If, on the other hand, there is a potential for commercial use of wool, attention ought to be given to both total yield and wool quality The heritability estimates in Table 9 10 indicate that wool characteristics will respond to selection Since wool production can be measured as the performance of both the male and female, selection within a large flock is relatively easy Measurable criteria are weight of fleece, clean scoured weight, length of staple, and fineness of wool

That growth rate and wool staple length can be improved simultaneously by selection is demonstrated by the data in Table 9 11 This study involved a large flock under range conditions in Colorado

In selecting for meat production only the economically important traits should be considered These will include a criterion for growth —e g , daily gain—and some measure of carcass value—e g , ratio of lean to fat

In seedstock flocks, weighing ewes periodically—annually or semiannually—is useful in determining the response to the feeding and management regime, identifying possible causes of poor breeding efficiency, and selecting for size of ewes in relation to weight of lamb produced at weaning or some identified age, such as when the lamb is 4 months old

If selection is applied for milk, meat, and wool simultaneously, genetic progress will be retarded in each trait, but apparently the genetic correlations are not antagonistic In Germany, Merinos have

been successfully selected for medium type wool, early maturity, and production of fat lambs (estimated milk yields of ewe) with a weight of 30 kg within 100 days of age (Haring, 1965). Emphasis in the selection index was weighted according to economic significance.

The improvement of sheep through selection can be achieved by eliminating low performance ewes, but far more important is the genetic progress that can be accomplished by proper ram selection. About 80–90% of the gains made in improving a trait such as fleece weight originate from selection between rams and only 10–20% derived from selection between ewes (Terrill, 1958). Progeny testing is a means for selecting rams, but unfortunately results become available too late in the active life of the rams. With proper selection, the best offspring should be better than the best ram used in the previous year. Reasonable genetic progress can be made by turning over generations as rapidly as possible—in both seedstock and local flocks. Even so, it would be desirable to carry forward progeny testing in the seedstock groups as means of increasing the precision of selection.

In the temperate zones it is evident the economic trends are such that in the future two main types of sheep will be required. One "type" will be needed for land areas of extreme climate and topography to be kept at low density with production being limited by nutrition and management costs. The second type will be used under intensive husbandry conditions. The latter must have high reproductive and growth potentials. Conceivably both types will also be required for tropical areas. For the extensive sheep production in areas of the tropics more emphasis should be given to milk production and pelt characteristics than in extensive range areas of the temperate areas due to the needs of the people. Too, there is a place for intensive sheep production in the tropics as small farm flocks producing lambs to be sold for fattening outside the farm. In these flocks the selection emphasis should be essentially the same as in the temperate zone.

Swine

Traits to Consider

Today, throughout the N-S 30° latitudes the native breeds of swine are being graded up or replaced by imports, principally from Europe and the U.S. This is due to the fact that imports will perform well if properly fed and managed.

In Puerto Rico, for example, the Duroc breed gained 12% faster

TABLE 9.12
Some representative heritability estimates for characteristics of swine

Characteristic	*Approximate range of heritability (%)*
Number of pigs farrowed	5 to 15
Number of pigs weaned	5 to 15
Pig weight at weaning	10 to 20
Litter weight at weaning	10 to 20
6-month pig weight	20 to 30
Daily post weaning gain	25 to 40
Feed per unit gain	30 to 50
Backfat thickness	40 to 60
Carcass length	40 to 60
Loin eye area	40 to 60
Percent of carcass in ham	40 to 60
Number of nipples	20 to 40

and required 8% less feed per 50 kg of gain than a native strain. The native sows averaged 10.1 pigs per litter as compared to 8.7 for Duroc, but the Duroc weaned 62% of the pigs born in contrast to 50% for native contemporaries (Carlo and Arcelay, 1962). Similar experience elsewhere, along with the recognition of the value of heterosis from crossbreeding, are the reasons for the replacement of native breeds. Since the use of introduced breeds has been accepted, few governments in tropical areas have been interested in setting up seedstock breeding establishments. This trend will probably continue unless problems of disease warrant closing importations.

In many countries of the tropics the market demand is divided between pigs of 30–40 kg and 80–100 kg. The former are used largely for festive occasions on which the pig is prepared whole, the latter supply the routine market. In some areas the demands for the two sizes are about equal. With a variable market it is difficult to establish breeding programs to maximize efficiency for both, nevertheless, the factors of primary importance in determining the efficiency are similar. Litter size, viability, weight per pig and per litter at weaning time, rate of gain between weaning and marketing, efficiency of feed conversion, and carcass acceptance are the important economic factors in swine breeding.

Estimates of heritability show considerable variation, yet most estimates (Table 9.12) indicate that several traits will respond to selection in a reasonable period of time. The heritabilities of litter size at birth and weaning weight of the litter are low. The low herit-

ability for pig weight at weaning suggests that weight at that age is largely a function of nursing ability of the sow rather than the pig's own genetic makeup. After weaning, the pig's own genes appear to exert their influence, as evidenced by the higher heritabilities for 6-month weight and post weaning gain.

Rate of gain and efficiency of feed conversion are related, but the strength of this relationship varies to some extent with breed and feeding conditions. Nevertheless, selection of breed or selection within breed according to daily gain from weaning to market weight is desirable because the fast growing pig is on hand fewer days which in turn requires less labor, permits faster turnover, and reduces the risks due to disease.

The response to selection for backfat thickness is rapid. After 10 generations of selection in Durocs for high and low thickness of backfat, the two lines differed by 2.6 cm or 68% of the initial mean. The corresponding differences between the two selected Yorkshire lines after 8 generations was 1.4 cm or 44% (Hetzer and Harvey, 1967).

Although fashions in type of pig have undergone more changes over the past 50 years than any other domestic species, there is now universal emphasis on rapid growth, lean carcass, and a type of carcass that will yield the greatest percentage of high priced portions. Perhaps this agreement on traits has led to the acceptance of a freer exchange of breeding stock than exists for other species. The apparent universal agreement on deemphasis of large amounts of fat in the hog carcass will continue to be the dominant factor in the selection of swine.

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10

Application of Mating Systems

There is obviously a need for genetic improvement of livestock in the N-S 30° latitudes. But what systems of mating will produce the types of livestock desired? Some animal breeders recommend adoption of the system of mating that will most rapidly bring about replacement of the indigenous stocks. Others see selective breeding within the indigenous groups as the key to improvement. The most logical approach to the problem, however, would seem to be to evaluate indigenous stocks and their environments before initiating any breeding program. An Expert Panel on Animal Breeding and Climatology (FAO, 1965) has recommended this procedure: (1) An objective evaluation should first be made of the presently available animals and the environments to which they are exposed. (2) In order to characterize the merits of the indigenous animals experimental work should be conducted to determine their ability to respond to improved environments. When sufficient merit appears to exist within these stocks, programs for improvement through selection should be implemented. (3) When the evaluation of indigenous stocks indicates the need for grading up or establishing new "gene pools," animals

should then be chosen for introductions that will be likely to contribute the desired end result.

Albeit the panel's approach is desirable, it involves practical problems of time, costs, and the need for trained personnel to supervise the breeding programs. Due to these limitations breeding in many locations will continue largely on an empirical basis. A much more profitable alternative would be for breeders to use the already established principles of animal breeding to determine the likelihood of success of one or more systems in their environments. With careful planning, satisfactory decisions can be made on this basis. The ensuing discussion deals with the possible merits of several systems of breeding.

INBREEDING AND LINEBREEDING

There has been little systematic investigation of the possibility of inbreeding and linebreeding for improvement among indigenous stocks in the tropics. Most of the evidence on the value of these systems comes from the temperate zone.

Dairy and Beef Production

Indications are that inbreeding increases the proportion of homozygous loci. This is evident from the increased incidence of recessive lethals in inbred groups. There is a general decline in level of performance and vigor associated with progressive increases in the degree of inbreeding. The more closely the characteristic is related to fitness, the more it appears subject to inbreeding depression, as demonstrated by the higher mortality in inbreds than in non-inbreds, particularly at early ages. The decreased differences between inbreds and non-inbred animals with advancing age suggests that inbreeding also delays the development of physiological processes (see Young *et al.*, 1969).

Results of inbreeding in beef breeds show that increased relationship within a group is associated with decreased growth and quality of the animals; but the detrimental effects of inbreeding tend to lessen as the inbred animals approach maturity. The magnitude and duration of inbreeding effects vary widely with breed, line, location, sex, and level of environment. Inbreeding of the dam impairs the preweaning weight of calves. Often the effect is greater than the inbreeding of the calves (Cundiff and Gregory, 1968; Warwick, 1968).

The amount of depression from inbreeding has varied among experiments, but in those concentrating on development of inbred lines the average decline has been 0.6 kg in weaning weight per percent inbreeding of the offspring. There has been 0.5–1.0 kg decline in weaning weight of calf per percent inbreeding of the cow and approximately .002 kg in daily post weaning gain per percent inbreeding of the calf. Fertility and calf viability are reduced 10–12% when the inbreeding of the cows averages 20% and that of the calves, 30%.

Limited evidence on the development of inbred lines for line-crossing indicates that this system offers no great promise in general practice for improvement of either beef or milk production. Although crossing of specific inbred lines may produce some superior individuals, the costs of development and maintenance of inbred lines of large animals usually make this system of breeding too costly to recommend (Young *et al.*, 1969; Cundiff and Gregory, 1968). In general, investigations of inbreeding versus line-crossing in beef breeds show reduced productivity with inbreeding and restoration of the losses when crosses are made between lines. The estimated heterosis for crosses among lines ranges from 3 to 5%, but in no instance have the line crosses significantly exceeded the high line (Brinks *et al.*, 1967).

Although the development of inbred lines for crossing does not seem warranted from existing evidence, it may be that indigenous groups that have been subjected to mild inbreeding due to isolation can profitably be maintained for crossbreeding. For example, preliminary evidence from Colombia indicates a high degree of heterosis when Romosinua (a Criollo breed, *Bos taurus* type) are crossed with local Zebu cattle. Results from Venezuela show that the small Criollo cow native to the Llanos area makes an exceedingly good mother and has little or no calving problems irrespective of the breed of sire she is mated to.

Crosses among six inbred lines of Holsteins (Young *et al.*, 1969) revealed that line crosses were 15% superior to the inbreds for milk, solids-not-fat, and milk fat production, as well as for percent solids-not-fat and percent of milk fat. But the line crosses averaged slightly lower in these traits than non-inbreds. However, significant differences have been observed among general combining abilities of lines, that is to say, some demonstrated more response from crossing than others.

Linebreeding is employed by a large proportion of the breeders of purebred cattle to maintain or increase the relationship to a particular individual. The major intent is to develop family lines to accentuate traits of the breeder's own choosing or those he feels

might sell best. This is typically referred to as associate mating, since the individuals mated are more alike in certain traits than the average of the herd or group. Few experimental investigations have been of sufficient magnitude to warrant definite conclusions on the merits of this system over outcrossing (mating among unrelated individuals). Present findings show that linebreeding is about equal to outcrossing in most breeds of cattle, with individual sire effects being more important than the effect of the breeding system.

Sheep Production

Inbreeding in sheep tends to depress traits associated with growth more than those associated with fleece. All phases of reproduction and viability seem adversely affected by inbreeding (Terrill, 1958). The birth weight of lambs out of inbred ewes is lower than that of lambs out of non-inbred ewes. Brown *et al.* (1961) also found a decline in all weights of lambs to 120 days of age, and concluded that inbreeding of both dam and lamb had an effect. Inbreeding of Merinos in Australia caused a reduction in body size, an increase in the variance of body weight, and a delay in age of peak reproductive performance, with inbred ewes taking one to two years longer to reach peak performance in reproduction or fleece production than non-inbred ewes. Inbred ewes also had more failures at parturition and greater losses of lambs both from birth to weaning age and less viability from weaning age to maturity (Bowman, 1966).

Only a few studies have been made on crossing inbred lines, but to date there is little evidence that line crossing will accomplish much more on the average than to repair some of the deleterious effects of inbreeding. Selected non-inbred groups are equally good or superior to those in the line crosses (Bowman, 1966).

Swine Production

Certain reproductive problems result from inbreeding of swine. Sexual maturity is delayed in both boars and gilts. Boars are less fertile, and gilts take longer to settle. Highly inbred boars also lack libido. The number of pigs born and raised tends to decline appreciably with inbreeding. And the frequency of the incidence of genetic defects increases (Craft, 1958). The number of pigs per little (litter size) is more difficult to maintain with inbreds than is growth rate. Incidence of stillborn pigs increases slightly with inbreeding of the

dam. But carcass characteristics and economy of gain seem little affected by inbreeding.

In spite of the disadvantages of inbreeding as a general policy, inbred lines have made a tremendous impact over the past 30 years on swine industries throughout the world. During the early 1920s experiments were started in the U.S. to develop inbred lines of swine. Some of these used purebred groups while others were based on crossbred foundations. Most of the experiments were coordinated by the Regional Swine Breeding laboratory at Ames, Iowa (Craft, 1958). Several methods of inbreeding were used. Some lines were inbred slowly while others were inbred more rapidly. Many lines were dropped after a year or two because of low fertility or otherwise poor performance.

A number of lines formed by crossing are now recognized as new breeds. These include:

Breed	*Approximate composition*
Beltsville No. 1	Landrace 74%, Poland China 26%
Beltsville No. 2	Danish Yorkshire 58%, Duroc 30% Hampshire 6%, Landrace 6%
Lacombe	Landrace, Chester White, Berkshire
Maryland No. 1	Landrace 63%, Berkshire 37%
Montana No 1	Landrace 58%, Hampshire 42%
Minnesota No. 1	Tamworth 52%, Landrace 48%
Minnesota No 2	Inbred Poland China 60%, Canadian Yorkshire 40%
Minnesota No. 3	Welch, Large White, Glouchester, Old Spot, Beltsville, No 2, Minnesota No 1, Minnesota No. 2, Poland China, San Pierre
Palouse	Landrace 53%, Chester White 47%
San Pierre	Berkshire, Chester White

The steps followed in development of the breeds were these: (1) Breeds were chosen that possessed the characteristics desired but were widely divergent genetically. (2) Foundation animals of high individual excellence and with a background of performance were chosen. (3) Breeding was conducted within closed herds. (4) Rigorous selection was practiced from the outset for factors affecting economy of production.

Performance in the new breeds has been good in many respects. Each has shown merit in crossing to produce market hogs. There are important genetic differences among the breeds in carcass characteristics. These breeds, as well as the lines developed from pure-

breds, have been crossed to produce the type of carcass desired without sacrificing growth rate or economy of gain. Carcasses from line crosses are generally intermediate between the parent lines for the individual traits.

In recent years, production and sale of "hybrid" boars have become important in the U.S. Several companies now specialize in producing boars bred to cross well with available female stock. In the largest operation, five major lines are kept to provide adequate crosses. Hybrid boars are produced by rotating sires from three or more related lines. These boars are sold for crossing on females in the herds of commercial producers.

Although inbred lines and linecrosses have shown advantages in swine improvement, it must be kept in mind that it is very costly to produce and maintain the lines. Since the production of inbred lines requires very close attention and extensive record keeping, it is likely that the swine industry in the tropics will continue to be guided by breeding establishments in the temperate zone.

Poultry Production

The experiences with poultry in the U.S. have been similar to those for swine. Again, a few large breeding organizations produce and maintain lines from which they develop males and females for sale to commercial breeders.

Although a great deal of research effort has gone into exploration of the development of inbred lines, this era seems to be passing. There are several reasons. The techniques used by hybrid corn breeders, that is developing and discarding hundreds of inbred lines, are not readily adaptable to livestock, especially cattle, sheep, and swine. The time and costs to produce and test lines adequately both as lines and in crossline combinations is excessive, and relatively few lines can be sampled and tested. Sales income, except from a few lines, has been low. Intensive selection with mild inbreeding has not produced a remarkably superior animal; and results from crossline matings have also not been exceptionally promising. Furthermore, the degeneration due to inbreeding has brought about practical problems in maintenance of highly inbred stocks for commercial usage.

In summary, inbreeding and linebreeding should be practiced only in herds of outstanding genetic merit. This makes these systems highly restrictive for general employment in herds of native breeds. On the other hand, inbreeding may be highly desirable when the breeder wants to concentrate the influence of one or several highly

selected individuals. This was done successfully in the development of the Santa Gertrudis breed when the bull "Monkey" and his sons were used quite extensively (Rhoad, 1949).

OUTCROSSING

There have been few experiments designed for direct comparisons of outcrossing with other systems of breeding. However, outcrosses have served as controls in numerous experiments involving development of inbred lines. As pointed out in the discussion on inbreeding, animals produced by outcrossing have on the average been superior to inbreds.

In a study designed to compare three levels of parental relationship on performance, conducted by the U.S. Department of Agriculture at Beltsville, Maryland, preliminary results have shown that Holsteins produced by outcrossing are superior to linebreds and to crosses of Holstein with Ayrshire or Brown Swiss in both feed efficiency during lactation and milk yield. Tests with beef breeds in the U.S. have indicated that on the average outcrosses are superior to linebreds or inbreds.

Even though outcrossing may give less spectacular results than crossbreeding and be less effective than other breeding systems in some herds, it has been responsible for bringing about many of the changes in groups of livestock. The trend has been to encourage outcrossing for the average commercial producer. With the advent of artificial insemination, this has become less expensive than purchasing sires or rearing them. Outcrossing can be effective too in dissortive matings which is what a breeder does when he attempts to make "corrective matings"—that is, to mate females mediocre or poor in one trait to a sire considered superior to outstanding in that trait.

Seemingly, outcrossing is the appropriate approach for a program of genetic improvement among indigenous stocks since inbreeding in many of the herds or flocks may already have reached the point of endangering fitness characteristics. Certainly in seedstock herds, outcrossing should be employed with selection as long as progress is possible.

CROSSBREEDING

Inter-matings among recognized breeds or lines developed within breeds have become widely used for commercial production of

poultry, swine, beef cattle, and sheep in several countries of the temperate zone. The main emphasis has been on obtaining heterosis, or hybrid vigor, which enhances economic returns. Crossbreeding is also in wide use in tropical regions, principally as a means of changing breed characteristics. In either situation it can be a very effective system with proper planning and control. Many people overlook this aspect. Crossbreeding as a system of mating is not a wonder worker, however. It will not automatically cure all ills. Like other systems, full benefit can be gained only by careful selection of parents.

Some livestock producers have expressed disappointment with crossbreeding because the heterosis shown at early ages in crossbred animals was not maintained throughout life. The age at which the estimate of heterosis is made is important in determining the level. The level of heterosis is normally the highest in the early stages of life and may decrease to the point there is little evidence at maturity or the late stages of life. One of the reasons for the wide use of crossbreeding in swine and poultry is that these animals are usually marketed at an age when the maximum benefits of heterosis are evident. Thus, if crossing is employed in tropical areas, the usual age for sale should be reduced; otherwise, the major benefits will go unrecognized.

For crossbreeding to be effective, sires of two or more breeds are needed. This can sometimes be a problem for the individual operator. For example, in a beef production enterprise, after the first round of crossing the percentage of different lines or breeds represented in the females of the herd will vary. More than one breed of sire is required in service at a time if combinations are to be made for maximum benefit of heterosis from crossing. This will require separation of breeding groups. These problems are not insurmountable, but they are of practical significance.

There have been numerous attempts to derive estimates of heterosis (expressed as the deviation of the average for crossbreds from the mean of the parent breeds) for breeds of several species in the temperate zone, but there have been very few studies of crossing among indigenous breeds. It is not likely that groups of temperate zone breeds will be imported to the tropics for crossing; but there is no reason to suspect that the level of heterosis obtained from crosses between native breeds will not fall within the same range as for others. In Venezuela crosses between Criollo and Zebu cattle showed 10–12% heterosis for average daily gain and up to 18% for 205-day weights (Plasse *et al.*, 1969). First generation crosses between Sahiwals from India and East African Zebu cattle in Kenya had an average milk yield 55% above that of the East African Zebus. Al-

though purebred Sahiwals were not available for comparison, resulting heterosis is suggested. Heterosis also accounts for the widespread use of crossing for beef production in the subtropical portions of Australia and the U.S.

Since crossbreeding seems to be a promising system of breeding for all climates, some of the expected gains among European breeds of cattle, sheep, swine, and poultry are given here as guidelines. These sections are followed with discussion of the possible merits of various degrees of crossing European breeds with local stocks.

Crossing among European Breeds for Beef Production

Up to the present, the Angus, Hereford, and Shorthorn breeds have been most widely used in balanced crossbreeding experiments. Results have been published from 15 studies in which two or more of these breeds and their reciprocal crosses have been compared. Two of the studies were conducted in Argentina, and the remainder in various areas of the U.S. Although there are differences between the breeds, these are relatively small; and the breeds can be considered generally similar in productivity, conformation, and carcass characteristics. The weighted average advantages of the crossbreds reported from the studies were as follows: 1.4% in calving rate, 3.0% in calf survival, 4.2% in proportion of calf crop weaned, 5.0% in weaning weight, about 2.5% in post weaning gain, and 0.6% in feed efficiency. Crossbreeding did not increase twinning or appreciably influence carcass grade, composition, or palatability. First estrus tended to occur earlier in crossbred heifers.

In comparisons of crossbred and purebred cows, the crossbred cows had an advantage of 4.3% in calf crop raised and 5.6% in calf weaning weight. Often crossbreds have not exceeded the best purebreds for individual characteristics, but in terms of "net worth," which includes the characteristics enumerated, the crossbreds have generally exceeded the purebreds.

Currently the Charolais breed is quite popular for crossing. The experimental evidence is still too limited to draw firm conclusions, but it appears that when Charolais sires are used on Hereford or Angus cows the crossbred calves are heavier at weaning and slaughter and produce carcasses with more lean than non-Charolais crosses. The Charolais crosses have carcass grades lower and less marbling than Angus, Hereford, and Shorthorn crosses (Warwick, 1968).

The amount of heterosis for birth weight and weaning weight is

influenced by the way the cross is made—e.g. whether the sire or dam is the larger breed. Maternal effects are important in these traits. Purebred cows are generally more fertile when mated to a bull of another breed and crossbred calves are more viable than purebreds. Heterosis tends to be higher in heifers than in steers, to be greater on a lower plane of nutrition, and to decline after one year of age. Crossbred cows usually have a higher conception rate to first service. On the other hand, crossbred bulls show no advantage in conception rate when used on the same type of cows (Mason, 1966).

In brief, the current consensus on the value of crossing among European breeds for beef production is that crossing can increase the net weight of calf weaned per cow bred up to about 15% with the advantages accruing as follows: 3 to 5% increase in calf livability, 3 to 9% increase in female breeding efficiency, and 5 to 10% higher milk production. Since these levels of advantages for crossing are of economic significance in beef production, crossbreeding in commercial beef production is on the increase.

Crossing of European Breeds for Dairy Production

Recent experiments in Britain and the U.S. involving both dairy and dual purpose breeds—Jersey, Guernsey, Holstein, Brown Swiss, Ayrshire, Red Dane, Red Poll, and Milking Shorthorn—have shown some heterosis for most traits. The estimates of heterosis (expressed as deviation of crosses from parental mean, with the plus signs indicating a possible economic advantage) from these experiments may be summarized as follows: viability of calves, +2 to +9% depending upon the breeds involved, with no evidence of significant advantage over the best parent; breeding efficiency of females, 0 to +15%, depending upon the measure used; number of calves born dead, +2%; number of cows culled for sterility, 0 to +10%; gestation length, near 0; growth rate as measured by body weight, 0 to +10%, depending upon the age at which the determination is made and the breed of the dam; and skeletal size (estimated by body weight and length), up to +3%.

The heterosis for milk yield in two-breed crosses ranges from −1 to +13%, with crosses having Holstein or Friesian breeding giving the higher values. Heterosis for milk fat ranged from +3 to +11%; fat percentage, −4 to +1%; persistency of milk yield, 0 to +3%, and efficiency of feed conversion during first lactation, 0 to +5%. The estimated heterosis for three-breed crosses from the weighted parental

mean ranges from 0 to +16% for milk yield; +1 to +17% for fat yield; 0 to +26% for fat percentage; 0 to +1% for percent solids-not-fat; −6 to +5% in persistency of milk yield; and +7 to +9% in efficiency of feed conversion (Pearson and McDowell, 1967).

There has been no clear evidence of heterosis in susceptibility to animal health problems although some pure breeds seem more susceptible than others. Crossing appears to overcome this deficiency as crossbred calves require fewer treatments for the usual calfhood maladies. Crossbreds show no advantage in this respect upon reaching lactating age (McDowell and McDaniel, 1968[a]).

It is not clear yet whether crossbreds survive longer or whether heterosis for milk production is maintained in older cows. If crossbreds are about 10% more likely to conceive than purebreds, this could be of significant economic importance in length of herd life and the portion of total life in lactation. Most of the experimental evidence indicates that the main advantages of the crosses are realized prior to and during first lactation. However, in a University of Illinois experiment Holstein-Guernsey crosses exceeded the parental mean by 10% in milk yield and 12% in fat yield in second lactation in contrast to advantages of 1–3% in first lactation.

Holsteins in the U.S. and Canada and Friesians in Europe are rapidly becoming far dominant in the dairy populations, therefore crossbreds must be more profitable than Holsteins else there would be little acceptance by commercial dairymen. In general, this has not been the case. So far the acceptance of crossbreeding in the temperate zones has been mainly in grading to Holstein or Friesian. Crosses of Holstein and Brown Swiss have most nearly approached Holsteins in total economic merit.

Crossbreeding for Sheep Production

Sheep breeders have long recognized that crossbreeding generally leads to increases in fertility and growth rate of the lambs. Increased milk yields, body weights, and wool production have also resulted from crossbreeding. In addition, more valuable market lambs may be produced by crossing mutton breed sires on wool type ewes, thereby increasing both body weight and wool production. Many experiments have established the benefits which can be gained in growth, general thriftiness, fleece weight, and wool quality from crossbreeding (Bowman, 1966).

Fertility, prolificacy, lamb viability and overall reproductive abil-

TABLE 10 1
Average percent deviation of crossbreds of the Hampshire, Shropshire, Southdown, and Merino breeds from the mean of the parent breeds based on index values and ewe characteristics

Trait	*Average of pure breeds*	*Percent deviation from purebred mean*			
		2 breed	*3 breed*	*4 breed*	*All crosses*
Index 1[a]	58 5	15 6	33 2	37 1	29 4
Index 2[b]	54 6	14 1	25 1	23 4	22 0
Index 3	59 2	15 4	32 8	36 8	28 9
Body weight, ewe	48 5 (kg)	2 8	6 5	12 1	6 5
Fleece weight, ewe	2 6 (kg)	8 6	6 9	3 4	6 9
Lamb wt/ewe bred	20 0 (kg)	18 1	40 9	47 7	36 4

Source Adopted from Sidwell 1964
[a]*Index 1 = Weaning weight of lamb adjusted for age + sex + grease fleece wt × 2.5*
[b]Index 2 = (Index 1/fall body weight of ewe) × 100
Index 3 = Index 1 without adjustment of lamb weight for age and sex of lamb

ity are generally higher from crossbreds than purebreds In the experiments of Sidwell *et al* (1964), the average increases in percent of lambs weaned from ewes bred were 2, 15 and 27% for two-, three-, and four-breed crosses, respectively, over the averages of the purebred parents The two-breed cross offspring tended to rank in the same order as the breed of dam for birth weight, weaning weight, and gain from birth to weaning The advantages for crossbreds were even more marked when expressed in three indexes (Table 10 1) The gains in lamb weight per ewe bred suggest a higher level of heterosis for this measure in sheep than in swine or cattle

In other experiments, emphasis has been placed on the use of crossbreeding for gains in mothering ability—i e , provide better ewes for commercial lamb production This system is currently used for approximately 50% of the commercial lamb production in many temperate areas

Crossbreeding for Swine Production

Crossbreeding has been widely accepted for commercial swine production with nearly 95% of the swine marketed in the U S and up to 50% of the swine in the tropics being breed crosses Where commercial swine production is moving into the tropics, a system of rotational crossing (use of three or more breeds) has been adopted Table 10 2 illustrates the expected heterosis for crosses between two breeds

TABLE 10.2
Expected heterosis from first cross and multiple breed crosses of swine.

Characteristic	Heterosis (%)	
	First cross[a]	Multiple cross[b]
Number of pigs farrowed	0	5
Survival	7	12
Litter size at weaning	10	20
Weight of pigs at 154 days	11	14
Total litter weight at 154 days	22	30

Source Adapted from Craft, 1958
[a] Boars and sows purebred, pigs crossbred
[b] Boars purebred, sows and pigs crossbred.

(first cross) and three or more breeds (multiple or rotational crosses) for several important economic traits.

A three-line (inbred lines from within a breed) or breed rotation cross has been recommended as an ideal method for commercial production; however, an objectionable feature of the breed rotation system is that it brings about rather drastic genetic changes in the offspring each generation unless the parents are similar in size. To avoid the cyclical variation arising from using boars of several breeds, breeders often attempt to capitalize on the excellent maternal characteristics of breeds like the Yorkshire or Landrace by using these breeds on the dam side. The rapid growth rate of the Duroc and Poland China are exploited on the sire side. The disadvantage of this approach is that it requires keeping herds of purebreds or purchasing stock to produce the lines for crossing. But some have adopted the system to produce a more uniform product than can be produced with any three-breed rotation.

Crossbreeding for Poultry Production

Breed and line-crossing for poultry production are practiced to a limited extent for egg production, but 90% or more of the broilers in many areas are produced from breeds or strains developed for crossing. Crossing is done to increase growth rate, improve carcass quality, and increase rate of feed intake. This same system—with the same strains or breeds—forms the basis of the commercial units in tropical areas. In Puerto Rico, Jordan, Venezuela, and Egypt, it has been shown that it is better to modify the environment and take advantage of the increased performance of improved strains and their crosses than to attempt to develop groups selected for greater suitability to

local conditions. In India both the white Leghorn and Rhode Island Red have proven far superior to the local breed, Desi. Hen-day egg production was 192, 191, and 38 for the three groups, respectively. Rearing mortality was about five times as great in the Desi and total mortality about twice as great as in the other breeds. Feed efficiency was also lower in the Desi. The White Leghorn male × Desi female cross had higher fertility and hatchability than the reciprocal cross, but the reciprocal had a higher survival rate and body weight at 4 weeks of age. All the crosses were higher in resistance to Newcastle disease than Desi or White Leghorns.

On the other hand, crossing of temperate zone and native breeds has not been as striking in Egypt. When the Fayoumi (F), Dandarawi (D), White Leghorn (WL), and Rhode Island Red (R) and their crosses were compared, the D was highest in fertility, the WL was superior in hatchability, and the R was the lowest of the four breeds for these traits. There was little difference in body weight of F, D, or WL up to 24 weeks of age, but R was 175 grams heavier. Crosses involving R were heaviest up to 24 weeks, but there was little difference among the other crosses; nevertheless, all crosses exceeded the average of the parents in weight. The crosses were higher than the average of the parents in egg production, with crosses containing D the best.

Application of Crossbreeding for Heterosis

It is evident that in exploitation of crossbreeding to capitalize on heterosis two factors must be kept in mind. The first is that the greatest degree of heterosis results from mating two breeds or the first cross. Thereafter, crossbreeding becomes largely a process of maintaining the heterosis. Some additional advantages over first crosses have been obtained by adding up to five breeds, but usually breed of sire effects are more important than the number of breeds, particularly after three breeds. It is generally conceded that three breeds are the *minimum that can be used in a rotational crossing system to maintain* approximately the level of heterosis obtained in the first generation. On the other hand, Kidder *et al.* (1964) recommended a two-breed crisscross plan as the most simple and adaptable system for many beef operations. They suggested that for the south Florida environment one of these breeds be Brahman and the other the breeder's choice from among European breeds. The theoretical makeup of crosses over six generations is illustrated in Table 10.3. In the crisscross, the second generation contains 75% of breed B, which reduces the level of heterosis. In subsequent generations the ratios are approximately 65:35. If maximum heterosis is realized at around 50%, the three-

TABLE 10 3
Theoretical makeup of crosses from crisscrossing of two breeds or rotational crossing with three breeds.

Generation number	Percent by breed	
	Crisscross	3-breeds
1	50 A 50 B	50 A 50 B
2	25 A 75 B	25 A 25 B 50 C
3	62.5 A 37.5 B	12 5 A 62.5 B 25 0 C
4	31.2 A 68 8 B	56.2 A 31.2 B 12.5 C
5	65 6 A 34.4 B	28 1 A 15 6 B 56 2 C
6	32.8 A 67 2 B	14 1 A 57 8 B 28 1 C

breed rotation does not deviate greatly from this level, except for the third generation where the level reaches 62.5% of one-breed influence. When more breeds are used, the influence of one breed is delayed until the generation where the input of breeds stops. The choice of system will depend upon the end result desired and the availability of sires.

The second factor to keep in mind is that crossbreeds among temperate zone breeds will often fail to exceed the high parent breed in all traits. Hence, the value of crossbreeding must be judged on "net merit." Table 10.4 shows that two-breed cross pigs did not exceed the high parent in a single trait; yet the advantage of the crossbreds, as measured by the weight of pigs sold, was 9% over the best parent. Table 10.5 represents another illustration of how the net return of crossbreds may rise or decline in comparison to the high parent when several traits are taken into account. The three-breed cross—Brown Swiss × Ayrshire × Holstein (S × AH)—gave a significantly higher return over feed cost than Holsteins. But this advantage was more than canceled out by poor viability and high veterinary costs. Other groups showed a small increase in net returns.

TABLE 10 4
Comparison of net values of crossbred swine and parent breeds

Trait	*Breed A*	*Breed B*	*Crossbreds*
Litter size farrowed (no)	10 0	6 0	8 5
Pigs alive at 180 days (no)	7 0	5 4	6 8
Survival (%)	70 0	90 0	80 0
Average weights			
Pig at 56 days (kg)	13 6	18 2	15 9
Pig at 180 days (kg)	81 1	108 2	100 3
Litter at 180 days (kg)	568 2	584 4	636 9
Average daily gain, 56–180 days (kg)	5	7	7

TABLE 10 5
Estimated returns ($US) per first lactation completed for two- and three-breed crosses among Ayrshires (A), Brown Swiss (S), and Holsteins (H) in comparison to Holsteins

Breed group	*Income over feed cost*[a]	*Health cost/lact*[b]	*Animal losses/lact*[c]	*Main cost /dry cow*[d]	*Net return*
A × H	6 00	8 00	−11 00	12 00	15 00
S × H	10 00	2 00	− 2 00	6 50	16 50
A × S	−43 00	−11 00	−16 00	3 00	−67 00
A × SH	12 00	−25 00	−23 00	5 00	−31 00
S × AH	27 00	−38 00	−95 00	16 50	−89 50
H × AS	16 00	6 00	−11 00	7 50	18 50

Source McDowell and McDaniel 1968
[a] Income over feed cost for first lactation with premium for percent fat and protein content
[b] Costs for veterinary services and drugs per lactation completed
[c] Value of animals lost prior to 150 days of first lactation per lactation completed
[d] *Maintenance cost for average days open × $0 50/day*

Crossing of Zebu and European Breeds for Beef Production

The results of crossing Zebu and European breeds have been somewhat different from those of crossing among European breeds, especially in the level of heterosis There have been hundreds of trials of crossing European beef breeds on Zebu or local stocks, but few have had contemporaries of both parents available. Estimates of heterosis from crossing European and tropical breeds come from the southern U.S., where experiments with beef breeds have produced 60 different breed combinations from 13 types of sires and 15 types of cows (Kincaid, 1962). The Brahma, Brahman-European crosses, and Santa Gertrudis crosses represented the Zebu types. These investiga-

tions are summarized as follows: Maternal ability, as measured by growth rate of calves from birth to weaning, showed European-Brahman crosses from crossbred dams to be slightly better than pure Brahman and much better than the average of the European dams. Crosses between European and Brahman types were significantly heavier at birth than the mean of the parental types. The first cross between European and Brahman types showed 11% heterosis for growth rate from birth to 15 months of age, or 7% above the high European breed. Pure European type calves grew about 7% faster than pure Brahman. Backcrosses to the European types were more effective than backcrosses to Brahman in keeping growth rate near the level achieved in the first cross. Carcass traits—not directly related to growth rate—showed little evidence of heterosis and the crosses were usually near the average of their parents. When slaughtered as yearlings, European breed steers graded higher in carcass and showed a higher percentage of lean and bone. Lean to bone ratio, based on a rib cut, favored the European breeds by a small amount. Tenderness and eating quality were reduced by crossing with Brahman.

In Queensland, Australia, crosses from mating Brahman and Africander bulls to Shorthorn and Hereford females performed better than either purebred parent. The crossbred cows were good mothers, as they produced 74–77% live calves as compared to only 56% for Shorthorn and Hereford. Experiments in Florida and Texas with Brahman and in South Africa with Africander cattle indicate that the European-tropical breed crossbred cows make excellent mothers. They are good milkers, have good fertility, and wean a higher ratio of their own weight in a calf than either pure tropical or European breeds (Mason, 1966). Many others have reported that European-native crossbred cows perform well and that crossbred calves from local breeds often gain 10–30% more rapidly than the regular native stock, even under rather poor environmental conditions. The viability of the crossbred calf is also good.

Studies conducted on ranches in Queensland, Australia showed that Zebu-European crosses gave higher returns than Herefords. Some of the advantages of the crosses are shown by the following data:

	Hereford	*Zebu crosses*
Age ready for sale (mo)	40	34
% Weaned	68.5	73.0
Dressed weight (kg)	270	276
Dipping cost/head (cents/yr)	65	43
Gross income/farm ($)	24,351	27,105
Return on capital investment (%)	5.3	7.4

The main advantages were in growth rate, viability, and the need for tick control which on a net merit basis gave 11.3% higher returns or \$2.10 per head of stock carried (McCarthy and Hodgson, 1970).

It is evident that rapid increases in beef production could be realized from crossing European type sires on native stocks. Two questions arise. What is the best plan for mating the crossbred cow, especially in a poor environment, and what is the most suitable European breed? At one time the Shorthorn was employed widely. Later, the Hereford gained in popularity. Recently, the use of Angus and Charolais—especially the latter—has expanded rapidly. Some have preferred only partial introduction of European breed inheritance by using the Santa Gertrudis, Charbray, or Brangus breeds. The most satisfactory breed of sire depends on several factors—namely, availability and quality of sires, level of environment, market preference, and likeliness of calving difficulty. For instance, a greater frequency of dystocia has been reported when Charolais bulls were used as compared to Angus, Hereford, or Santa Gertrudis. Certainly the bull must be from a breed that can live and breed in the local environment. Often this is the deterrent in the use of pure European type bulls.

Crossing of Native and European Breeds for Dairy Production

At present there is little information available for estimating the amount of heterosis that can be expected by crossing European breeds with Zebu or indigenous type cattle. This is because the crossings have usually involved small numbers of one type or the other. Most of the time introductions have been made through sires or semen. Although there was insufficient Zebu controls in the U.S. experiments with Red Sindhi and Brahman, there was some evidence of heterosis for growth rate, milk yield, and tolerance to high temperature stress (Branton *et al.*, 1966). Growth rate of the F_1 Red Sindhi-Jersey crosses was especially high. Although the Red Sindhi is considerably smaller than the Jersey, both male and female F_1 crosses exceeded the Jersey in size, as illustrated in Figure 10.1.

Crossing of Zebu—in this case Red Sindhi—with European breeds changes not only body size but also body configuration, as shown by the Red Sindhi-Jersey crosses in Figure 10.2. The hump is barely evident up to ½ Zebu (lower left) and disappears in ¼ Zebu crosses (lower right). The sloping rump and length of head appear dominant, as these characteristics show in all the fractional crosses. The size of ear and the udder characteristics, such as shape, have a

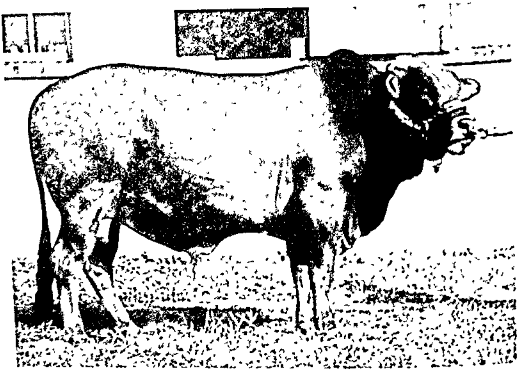


FIGURE 10.1
A Red Sindhi-Jersey F_1 crossbred bull representing an example of the crossbred exceeding both parent breeds in growth rate. At two years of age he weighed 550 kg, as compared to 385 kg for contemporary Red Sindhis and 450 kg for Jerseys. (Courtesy Agric. Res. Service, USDA)

direct relation to the proportion of Zebu genes in the cross. As pointed out in Chapter 5, the short hair coat of the Zebu is dominant to that of the Jersey in these crosses. The general conformation and the udders of six first generation Red Sindhi-Jersey crosses in Figure 10.3 show that within any one combination the conformation of the animals is as uniform as in most pure breeds. Likewise, the percent coefficient of variation for milk yield for first generation crosses was similar to that of Jerseys (Branton *et al.*, 1966).

Stonaker *et al.* (1953) reported that Jersey-Red Sindhi crosses were superior to pure Red Sindhi in all performance traits. Over twice as many crossbred cows as Red Sindhis remained in the herd for a period of six lactations. The researchers estimated that if total production for the number of years cows remain in the herd were computed on age of first calving and production in the first lactation, the production of F_1 crosses would exceed 2.09 times that of Red Sindhis.

In general, first generation European-Zebu crosses have averaged about 15% higher in body weight at birth, 12–20% higher at one year of age, and 6–20% higher at two years of age than contemporary pure-

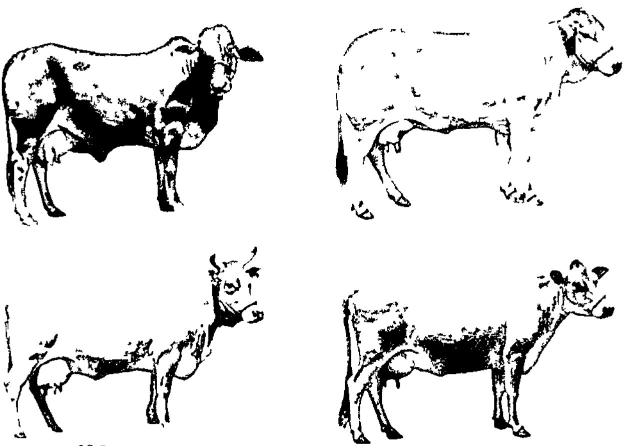


FIGURE 10.2
Illustration of changes in phenotypic characteristics produced by crossing Red Sindhi and Jersey. (Upper left, Red Sindhi, upper right, ¼ Jersey, lower left, ½ Jersey, and lower right, ¾ Jersey.) (Courtesy Agric. Res. Service, USDA)

FIGURE 10.3
A group of first generation crosses between Red Sindhis and Jerseys as they appeared during first lactation. Their average age of first calving was 25.6 months. These six averaged 3686 kg of milk and 227 kg of fat in 305 days during first lactation. (Courtesy Agric. Res. Service, USDA)

bred Zebus. The age of first calving for crossbreds is also lower. Pearson *et al.* (1968), among others, found no difference in frequency of abortion in natives and ¾ Jersey–¼ Criollo crossbreds, while others, such as Singh and Desi (1964), reported higher frequency of abortions in crosses. Other evidence from India has shown 7% abortion in natives, 12% in F_1 crosses, and 16% in ¾ native crosses.

TABLE 10.7
Group means and percent deviation from pure native herdmates, either selected or random bred, for $^1/_4$, $^1/_2$, $^3/_4$, and $^7/_8$ crosses with various European breeds.

Breed group	No. countries	No. breeds	No. records	Milk yield Mean	Milk yield %	Lact. length Mean	Lact. length %	Calving interval Mean	Calving interval %	Age 1st calving Mean	Age 1st calving %
FROM SELECTED GROUPS											
$^1/_4$ Jersey	1	1	50	1944	123	345	98	399	97	34 0	92
$^1/_4$ Ayrshire	1	2	49	1526	141	286	108	419	95	40.0	93
$^1/_4$ Friesian	1	1	24	1548	163	280	108	417	103	37.5	93
$^1/_2$ Jersey	1	1	125	2042	140	315	92	396	93	28 6	78
$^1/_2$ Ayrshire	2	2	562	2109	166	310	113	384	87	34 9	80
$^1/_2$ Friesian	1	2	262	2859	183	307	109	423	97	36.1	87
$^1/_2$ Br. Swiss	2	3	85	3172	176	326	109	421	92	32 4	78
$^3/_4$ Ayrshire	2	2	69	1459	135	273	109	383	87	38 6	89
$^3/_4$ Friesian	1	2	317	2388	168	306	109	416	106	36 4	88
$^7/_8$ Ayrshire	1	1	25	780	77	191	78	–	–	47.0	98
$^7/_8$ Friesian	1	1	218	2264	128	299	101	462	110	36 0	94
FROM RANDOM GROUPS											
$^1/_4$ Jersey	1	1	424	613	359	157	275	392	105	40 4	99
$^1/_4$ Ayrshire	1	1	27	1842	228	202	100	443	106	45 5	92
$^1/_2$ Jersey	2	2	60	2124	242	292	115	387	81	35 1	70
$^1/_2$ Ayrshire	1	1	77	2058	173	282	123	382	93	37 0	76
$^1/_2$ Friesian	4	4	542	1628	136	276	117	450	112	33 3	76
$^1/_2$ Shorthorn	1	1	311	2111	168	278	117	399	98	36.7	81
$^3/_4$ Jersey	1	1	59	2364	188	298	126	359	88	28.9	68
$^3/_4$ Ayrshire	1	1	23	2106	261	310	153	419	94	38.4	78
$^3/_4$ Friesian	2	2	119	2130	136	316	134	440	104	35 1	82
$^3/_4$ Shorthorn	1	1	59	1903	151	309	130	463	114	34 2	81
$^7/_8$ Jersey	1	1	25	2870	228	324	137	383	94	26.7	63
$^7/_8$ Friesian	1	1	22	2095	172	283	120	450	111	42 4	100

uated for their response to selection before being lost by crossbreeding. The results from crossing are particularly impressive in view of the fact that often the European bulls were bred to the lower half of the native cows in the herds, while the better cows were mated to native bulls.

In the herds with the two pure types, the pure European breeds excelled in milk yield. Although these herds were better than average herds found on local farms, the pure European breeds were subjected

to environments near similar to those of the native breeds Comparison of the performance of crossbreds and pure European breeds is not included in the summary, but in herds where they were together, the pure European cattle tended to excel the crosses in total milk yield and yield per day of lactation, as illustrated by the following data from a herd in Venezuela

Group	Lact length (day)	Milk (kg)	Milk/day of lact (kg)
Holstein	287	4018	14 0
7/8 Holstein Criollo	290	3643	12 6
3/4 Holstein Criollo	285	3560	12 5
1/2 Holstein Criollo	274	3087	11 3

In the majority of the herds the pure European breeds were poorer than crosses in viability, age of first calving, frequency of abortion, and especially reproduction as measured by calving interval In spite of the default in the crosses, the pure European breeds had longer calving intervals, than the native breeds, their yields of milk per day of calving interval were higher (Kassir, *et al*, 1969), as illustrated by the following data on native breeds and Friesian-native crosses The deviations without minus signs are economically advantageous, those with minus signs, disadvantageous

	Avg for native	% Deviation from native			
		1/2 F	3/4 F	7/8 F	Fr
Age 1st calving (mo)	44 9	20	12	14	22
Calving interval (da)	396	−20	−31	−18	−20
Dry period (da)	182	−47	−49	−73	−57
Service period (da)	103	−16	6	− 2	11
Lact length (da)	219	48	47	50	55
Milk/da cal interval (da)	2 6	77	78	101	102

Table 10 7 shows the average performance of crossbred groups with various amounts of breeding Ayrshire, Jersey, Friesian or Holstein, Brown Swiss, and Shorthorn There is some variation in performance among the crosses related to the European breed involved, but more of this appears associated with small numbers and possible differences in quality of sires than real differences in combining ability In general, it seems that all European breeds combine satisfactorily with native breeds Currently Holsteins are employed in the greatest numbers, but there is no clear evidence that Holsteins give better results than other breeds

Notwithstanding the fact that employing a small breed, such as

A number of investigations, for example that of Amble and Jain (1967), have indicated a decrease in milk yield as the proportion of European blood deviated from 1/2 or 5/8 on either side. Webster and Wilson (1966) showed this was also true for number of calvings: the

TABLE 10.6
Average performance of "selected" and "random" groups of native cattle versus average performance of crosses with 1/4, 1/2, 3/4, and 7/8 fractions of European breeding and pure European breeds.

Breed group	No. of countries	No. of breeds		No. of records	Milk yield		Lact. length		Calving interval		Age 1st calving	
		Nat.	Eur.		Mean (kg)	%[a]	Mean (days)	%	Mean (days)	%	Mean (mo)	%
PURE NATIVE												
Selected	3	3		1464	1444		278		437		42.4	
Random	6	6		2338	631		190		400		41.8	
Avg. all	7	8		3802	944		219		410		42.0	
1/4 EUROPEAN CROSSES												
Selected[b]	1	2	2	123	1727	120	313	113	419	96	36.0	85
Random	2	2	2	431	633	100	158	83	393	98	40.5	97
Avg. all	2	4	3	554	875	93	192	88	397	97	39.5	94
1/2 EUROPEAN CROSSES												
Selected	3	3	4	974	2339	162	310	112	400	92	35.0	83
Random	4	4	4	990	1843	292	278	146	414	104	35.0	84
Avg. all	6	7	5	1964	2088	221	293	134	408	100	35.0	83
3/4 EUROPEAN CROSSES												
Selected	2	2	2	386	2222	154	300	108	456	104	36.8	87
Random	3	3	3	210	2074	329	312	164	441	110	34.9	83
Avg. all	4	5	3	596	2170	230	304	139	450	110	36.1	86
7/8 EUROPEAN CROSSES												
Selected	2	2	2	243	2111	146	288	104	462	106	37.1	88
Random	1	1	2	27	2323	368	295	155	430	108	37.8	90
Avg. all	3	3	3	270	2125	225	288	132	460	112	37.1	88
PURE EUROPEAN												
Native[c]	6	6		1130	2083		244		416		42.6	
European	6		6	1273	2974	144	333	136	433	104	31.3	73

[a] Average percent deviation from native herdmates
[b] 1/4 European breed, 3/4 native
[c] Herdmates to pure European breeds only, not included in mean for Pure Native group

average numbers were 5 0 for ½ and ⅝ European crosses, and 3, 2 5, 2 0, and 1 5 for ¾, ⅞, 15/16 crosses, and pure European, respectively These studies represent small groups in separate herds, but when they are put together contrary trends emerge

Table 10 6 contains a summary of the average performance of pure native, various fractional crosses with European breeds, and pure European breeds for several traits important in dairy production These values were derived by pooling data from 48 herds throughout the tropical world at locations of less than 2000 meters elevation In order for a herd to be included, it had to have two or more groups that were contemporaries and at least 10 milk records per breed group The pure Europeans were required to have at least pure native contemporary herdmates There are 9 breeds included in the pure native grouping These were divided into "selected" and "random" groups —the "selected" group including herds that had been in existence several generations, and the "random" group consisting of herds of newly assembled native stock or herds in which little or no attention had been given to sire identification and selection There were 6 pure European breeds, 5 of which were represented in the crosses The European breeds in the ¼, ½, ¾, and ⅞ crosses are given in Table 10 7 The group means in Table 10 6 are based on all records available and the percentages represent the ratio of the crossbred mean to that for the native herdmates

Even though all breed groups were not in the same herds and there were variations in levels of feeding and management, disparity in the number of sires of European breeding used, and no doubt differential selection in the quality of sires, rather consistent patterns emerge for crossbreeding, especially when the "selected" native was the base stock For milk yield, the ½ crosses were 62% above the average for native herdmates The ¾ and ⅞ crosses were 40–50% higher, but the ¼ European crosses were considerably lower Length of lactation period tended to increase with the proportion of European breeding, but age at first calving tended to decline Calving interval in both the crosses and pure European group was as long as for the native group cattle, and sometimes longer Due to the fact that the average milk yield of the "random" group was extremely low, the increase by crossbreeding was markedly higher than for the "selected" group Based on the average yield for crosses from a random group of native stock, it appears that one or two generations of crossing with European breeds can provide as acceptable milk producers as starting with "selected" native stock This suggests that unless the crossing is to be carried on to produce bulls for distribution to other farms, "selected groups" already in existence should perhaps be eval-

the Jersey, would provide animals more suitable to warm climates from the standpoint of resistance to thermal stress and thereby perhaps more efficient, Holsteins will continue to be popular for crossing. The Holstein or Friesian has several factors in its favor, viz the crosses will produce higher lactation yields than crosses with other breeds and there is a larger population to draw from. The breed has the most extensive progeny testing program in both the temperature and warm climate regions. Its light-colored body fat is preferred for beef because it does not make the carcass appear as fatty as yellow fat, which is characteristic of the Jersey. The returns from the sale of day-old or very young Holstein cross calves in the market will ordinarily be enough to more than cover breeding costs, whereas returns from Jersey crosses will not. The Brown Swiss has many of the features of the Holstein and has been popular for crossing, chiefly in Latin America, but it is declining due to the small number of high quality sires available.

Probably the best way of determining the most suitable breeds or crosses is to examine their potential on the basis of "total dairy merit." The estimated total numbers of females needed to maintain herds of native, crossbreds and European types which would provide a total daily herd output of 250 kg of milk throughout the year are presented in Table 10.8. The requirements of females in lactation, dry cows, and young stock are based on the group averages from Table 10.6. These include level of milk yield, and length of lactation, as well as estimates of calf and cow losses per year. Because of short lactations, the ratio of dry cows to milking cows range from about 1:1 in the "random" native types to 1:4 in the pure European. The non-lactating groups are included to show how viability and age of first calving determines the required total herd inventory of females. The low values for percent herd efficiency (number of females in lactation/total herd inventory × 100) for the random group show that in addition to milk yield per cow, factors such as length of lactation, calving interval, age of first calving, and animal losses contribute immensely to the estimate of dairy merit. The combined picture is what is most important to a commercial dairy operation. Studies on four separate breeds of native types gave estimates for dairy merit similar to those for the native groups (McDowell, 1971).

Based on the performance of Jersey-Hariana crosses and pure Hariana at Haringhata, India, the herd size required to produce 700 kg of milk per day would be 325 females for F_1 crossbreds as opposed to 910 for pure Hariana—a reduction of 64%. The crosses were not only superior in milk yield but also in other traits important in total dairy merit. Although feed per animal was higher for the crosses, herd

TABLE 10.8
Average expected performance of various groups and numbers of females of each group required for a herd that will provide 250 kg of milk per day throughout the year

Trait	Native: Selected	Native: Random	Crosses[a]: 1/4	Crosses[a]: 1/2	Crosses[a]: 3/4	Pure European
GROUP AVERAGES						
Lactation milk (kg)	1444	631	875	2088	2170	2974
Milk yield/day (kg)	5.2	3.3	4.6	7.1	7.1	8.9
Calving interval (days)	437	400	397	408	450	433
Lactation length (days)	278	190	192	293	304	333
Age at first calving (mo)	42.4	41.8	39.5	35.0	36.1	37.1
Calf mortality (%)	10	24	15	10	17	20
Cow losses/year (%)	12	22	14	10	20	21
NUMBER OF FEMALES REQUIRED						
In lactation	48	76	54	35	35	28
Dry cows	27	68	22	14	17	8
Young stock						
36–42 months	17	34	19	0	4	4
25–36 months	18	36	20	10	16	8
13–24 months	26	38	21	11	17	9
4–12 months	27	42	22	12	18	10
Females born/year	30	62	32	21	20	14
Total herd[b]	154	307	164	86	110	69
Herd efficiency (%)[c]	31.1	24.8	32.9	40.7	31.8	40.6

[a] Proportion of European breeding
[b] Includes all females 4 months and older plus 20% of female calves born per year
[c] Number in lactation/total herd × 100

feed requirements would be about 63% less for the crossbred herd (325 crosses vs 910 Harianas). Thus, the feed energy per kilogram of milk produced by the pure Hariana herd would be more than twice that for a crossbred herd providing a similar quantity of milk (McDowell, 1971).

Crossing of Native and European Breeds for Sheep Production

Numerous breeds of sheep as well as cattle, have been imported into the tropics. The performance of crossbreds, principally first generation, has been acceptable. For instance, in Egypt, *Suffolk × Ossimi*

crosses were 30% heavier at birth than Ossimi and 37% larger at 6 months of age.

Crossing with European breeds produces larger sheep with an intermediate type wool. But often feed supplies are so limited that the increased growth potential is not realized. And the wool from the crossbreds is not readily accepted for home weaving. As a result of these factors, plus a greater interest in milking qualities than in growth or wool in warm climates, crossbreeding has not been widely accepted by either small flock owners or nomadic tribes. The prospects for crossing among groups of sheep in the warm climates are discussed further in Chapter 15.

GRADING UP

Grading up, as defined in Chapter 9, is no longer extensively employed in the temperate zone; but it continues in wide use in the warm climate regions, although it has had mixed results. For instance, in Israel the grading up of local Syrian cattle with Friesians has been quite successful. Yet in Iran, India, and numerous other countries, the first generation crosses performed well but the backcrosses (second generation of grading) to the introduced breed often performed more poorly than the $^1/_2$ to $^5/_8$ combinations (Amble and Jain, 1967). The usual reason given is that the crosses "lost their adaptability," which implies changes in the basic physiological processes of heat regulation. A more likely explanation is that the poor performance stemmed primarily from a change in size. The indigenous stocks were typically smaller than the "improved type." There was sufficient hybrid vigor in the first generation crosses for them to perform well in the local environment. In the backcrosses to the introduced breed ($^3/_4$ and $^7/_8$ of improved breed) hybrid vigor declined and the inheritance for body size increased, thereby making the energy needs for body maintenance materially higher. This resulted in the crossbred being subjected to a high degree of nutritional stress, which in turn led to a general breakdown in body functions and poor performance.

In other countries, such as Venezuela, two or even three crossings to an introduced breed of dairy cattle have proved reasonably successful before "degeneration" set in. Here too, the major cause of lowered performance, above the $^3/_4$ or $^7/_8$ level of introduced breeds, may have been due to limitations of feed energy in relation to requirements for maintenance and production.

Grading up of local stocks has several advantages: it is the cheapest means of eventually replacing the local stock since only males or

semen are needed, with semen use, area or country programs can be rapidly initiated, it permits capitalizing on progeny test results from areas where it is already practiced, and it permits gradual adjustments of local farming methods and development of the animal husbandry skills needed to handle the improved stocks No doubt "grading up" will continue to be practiced It is hoped that there will be a simultaneous growth of awareness of the need for improvement in the level of environment with each generation

DEVELOPMENT OF STRAINS FROM CROSSBRED FOUNDATION

The majority of the recognized breeds in the world today have resulted from the crossing of two or more groups Since the 1930s there has been extensive experimentation with crossing to improve existing stocks The purpose has been to incorporate into the basic population desirable traits from other breeds and then attempt to fix the characteristics of the crossbred types As pointed out earlier, this has been widely practiced with swine and poultry There are also several recognized strains or breeds of sheep and cattle that have been developed by this method (Table 10 9) Representatives of several of these new strains are shown in Figures 10 4–10 11

Probably the most prominent of the new breeds of cattle is the Santa Gertrudis Initially, the approach in development of this breed was similar to that employed by swine breeders There were large numbers of crosses made and eventually a bull, called "Monkey," showed up with most of the qualities desired It was through use of his sons that the breed evolved

Other groups of cattle that have attained prominence are the Beefmaster in the U S , the Bonsmara of South Africa, and the Jamaica Hope of Jamaica These were developed through intensive selection from a "gene pool" of relatively small numbers

The new breeds have been accepted reasonably well They have certain advantages but are not necessarily the solution for all the tropics The Santa Gertrudis is the most popular imported breed in the Philippines, as well as in areas of Latin America and Australia It seems to have a number of good qualities, such as hardiness and good growth rate, but it is not held in high esteem by many due to poorer than desired libido in some of the males and long calving intervals in females The Jamaica Hope has been well accepted in Jamaica, but it too may have limitations in reproductive efficiency, as measured by calving interval and services per conception This

TABLE 10.9
Some recognized breeds developed from crossbred foundation

Name	Theoretical composition	Origin
	CATTLE	
Bonsmara	$^5/_8$ Africander, $^3/_8$ Shorthorn	South Africa
Santa Gertrudis	$^5/_8$ Shorthorn, $^3/_8$ Zebu	United States
Beefmaster	$^1/_2$ Zebu, $^1/_4$ Hereford, $^1/_4$ Shorthorn	United States
Indubrasil	2 breeds of Zebu	Brazil
Droughtmaster	Admixture of *Bos taurus* and *Bos indicus*	Australia
Quasar	$^1/_2$ *Bos indicus*, $^1/_2$ *Bos taurus*	Australia
Brangus	Brahman, Angus	United States
Brayford	Brahman, Hereford	United States
Charbray	$^3/_4$ Charolais, $^1/_4$ Brahman	United States
Jamaica Hope	Jersey, Zebu	Jamaica
Jamaica Red	Red Poll, Zebu	Jamaica
Jamaica Black	Angus, Zebu	Jamaica
Occampo	Holstein, Zebu	West Indies
Barzona	Africander, Hereford, Santa Gertrudis	United States
	SHEEP	
Columbia	Lincoln, Rambouillet	United States
Cornedale	Lincoln, Leicester, Merino	United States
Panama	Rambouillet, Lincoln	United States
Soviet Corriedale	Lincoln, Rambouillet	USSR
Romeldale	Romney, Rambouillet	United States
Thribblecross	Cotswold, Spanish Merino	United States
Dormer	Dorset Horn, German Merino	South Africa
Polwarth	$^3/_4$ Merino, $^1/_4$ Lincoln	Australia
Targhee	Rambouillet, Corriedale, Lincoln	United States

has probably resulted from the inbreeding required in development of the breed. The Jamaica Hope's performance in commercial herds in Jamaica varies with the level of environment (Wellington, *et al.*, 1970). Until recently there have been few other breeds available in the same herds, hence there was no way of determining whether this breed performs better than other breeds—e.g., the Holstein. But preliminary evidence suggests the Jamaica Hope has better breeding efficiency than recently imported Holsteins in dairy herds of Jamaica.

Where small numbers are available to develop a new breed, the degree of success is critically associated with careful selection of individuals. Unfortunately, this concept has not always prevailed. Rhoad's attempt to recapitulate the makeup of the Santa Gertrudis (Rhoad, 1949) as precisely $^5/_8$ Shorthorn and $^3/_8$ Zebu was a disservice

FIGURE 10 4
Two year old Bonsmara heifers representing a breed developed from crossing Africander with Shorthorn in the Union of South Africa This breed has become popular for beef production It is especially good in reproductive efficiency and has high tick resistance (Courtesy J C Bonsma, University of Pretoria)

FIGURE 10 5
A bull of the Quasar strain, which was developed from mating pure *Bos indicus* (Sahiwal) bulls on selected Shorthorn dams This strain has become quite popular in northern Queensland, Australia, as it is a hardy grazer and has good tick resistance (Courtesy D F Dowling, University of Queensland)

as it led planners to believe that this ratio of two breeds was desirable in all cases. This narrow view has caused planners to forget that maximum flexibility in creating "gene pools" has been the basis of success for most of the strains of cattle, swine, and sheep accepted by commercial producers.

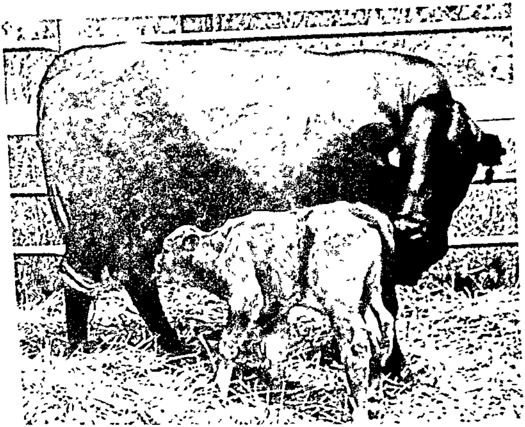


FIGURE 10 6
A Quasar cow with her calf by a Charolais bull The Charolais-Quasar cross is being used to develop an additional strain—Charsar—which has the improved growth rate and carcass composition of the Charolais (Courtesy D F Dowling, University of Queensland)

If animal breeders are to be successful in developing groups with high suitability to particular environments, rigid plans such as the one shown in Figure 10.12 should be avoided. This scheme proposes development of a new strain by crossing Brown Swiss with locally available Zebu cattle (Sahiwal) beginning with a fixed plan to obtain the initial groups intended for selective breeding. Among the disadvantages of this approach would be the 20 or more years required to reach the planned combination (third generation) for intensive selection. Also, there is no assurance that the $^5/_8$ Brown Swiss-$^3/_8$ Sahiwal represents the best combination for the anticipated environment. Furthermore, such a procedure, except with large numbers, would restrict the opportunities for selection for a long time. It would be more appropriate to carefully select the "improver breed," make a first generation cross or possibly a backcross to the improver breed, depending upon the anticipated level of environment, and then initiate crossbred matings with intensive selection.

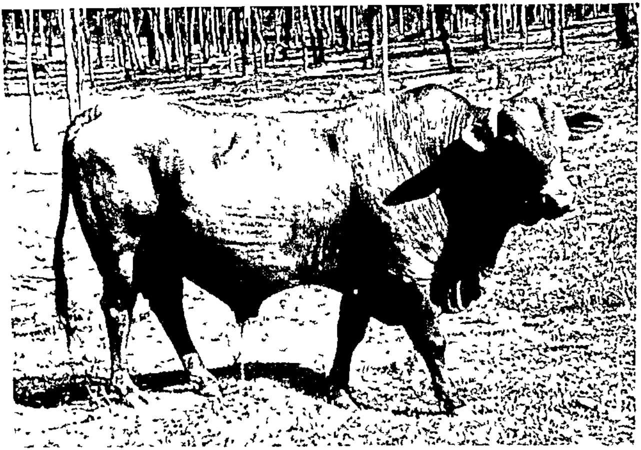


FIGURE 10 7
A Droughtmaster bull representing a strain developed in Australia for beef production from crossing several breeds of *Bos taurus* with Zebu (1/8 to 1/4 Zebu) This is another strain popular for beef production in northern Australia (Courtesy J K Loosli, Cornell University)

A more effective approach was the one taken in Louisiana by Hollon *et al.* (1969), in which the concept of a "gene pool" was employed. For the initial pool, a selected group of Red Sindhi-Jersey crosses, along with purebred Jersey and Holstein females, were crossed for one and two generations to selected progeny tested Holstein and Brown Swiss sires. First and second generation crossbred sires were then sampled across the crossbred female groups. This meant in some instances, inter se matings and in others, an expansion of gene combinations from which to choose. Compared to contemporary purebred Holsteins, the crosses resulting from the use of the crossbred sires averaged 22% less in milk yield. Thus, it appeared that the initial gene pool had not attained the desired objective—namely, exceeding the performance of Holsteins in production and reproduction efficiency. The gene pool was reopened. Since the combinations with the Red Sindhi were the poorest, these were eliminated as rapidly as possible and additional infusions of Holstein and Brown Swiss breeding were tested prior to further sampling of crossbred sires. (A similar procedure was followed in development of the

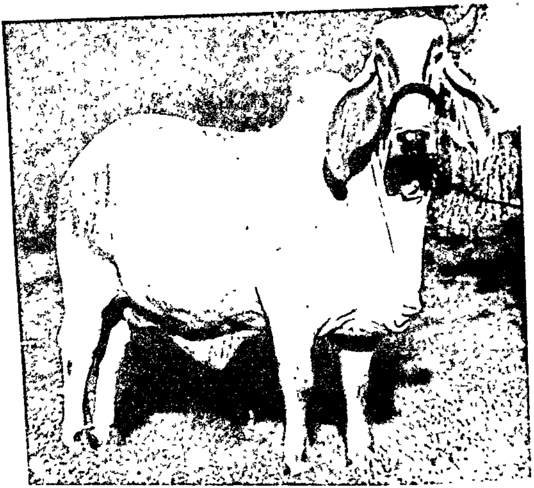


FIGURE 10 8
An Indubrasil cow representing a breed developed in Brazil from crosses of two breeds of Zebu originating in India This is one of very few breeds developed in modern times from crosses of two Zebu breeds Its performance under extensive grazing conditions in Brazil is reported as good (Courtesy J S Veiga)

Jamaica Hope.) When the level of environment at the Bodles Experiment Station in Jamaica was considered sufficient to support a more productive and larger animal, a partial infusion of Holstein breeding was introduced to further increase milk yields. These experiments clearly indicate the value of keeping the gene pool flexible, rather than adhering to the concept that once a population is closed for selective breeding it must remain closed.

In summary, crossbreeding in one form or another appears to offer the most practical approach for improvement in many situations. It can be utilized effectively in various ways. Where native livestock are reasonably satisfactory, genes may be introduced by limited crossing with an improver stock before selection is initiated. If the native animals are so inferior that they should eventually be replaced, con-

FIGURE 10 9
A Jamaica Hope cow representing a dairy breed developed in Jamaica from crosses of Jersey and the Sahiwal breed of India This cow produced 6 350 kg milk in 312 days, after calving at 5 years, 6 months of age (Courtesy L E McLaren, Ministry of Agriculture and Fisheries, Jamaica)

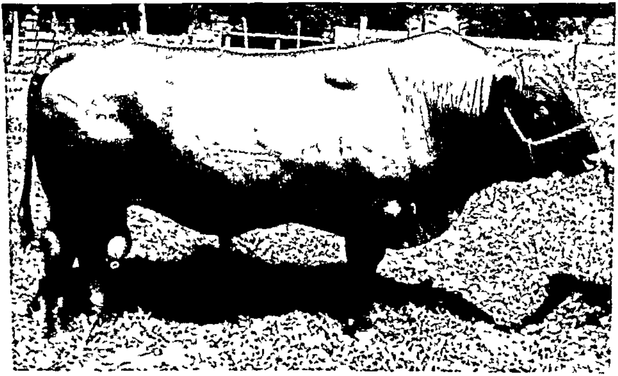


FIGURE 10 10
A Jamaica Red bull representing a beef breed developed in Jamaica from Red Poll-Zebu crosses The breed is polled and dark red in color It has been selected for growth rate under grazing conditions (Courtesy L E McLaren, Ministry of Agriculture and Fisheries, Jamaica)

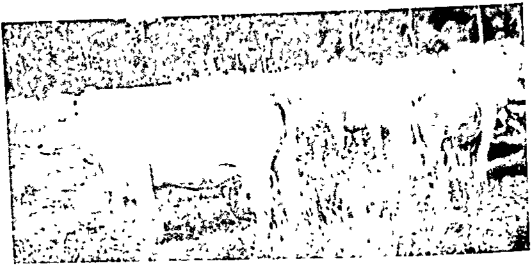


FIGURE 10.11
Herd of Charbray cattle, a strain that is becoming quite popular in the southern U.S. It was developed from crosses of Charolais (¾) and Brahma (¼).

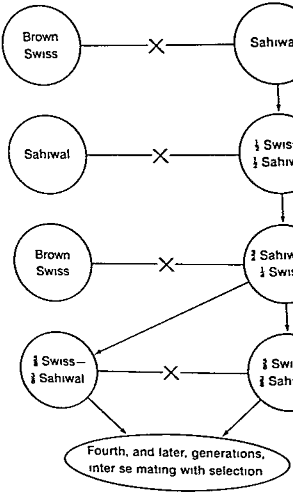


FIGURE 10 12
Illustration of a proposed breeding plan for development of a new strain for dairy production

tinued grading up to improved stock and rigid selection should follow the initial crossing Sometimes, however, crossing among local types may result in sufficient hybrid vigor to be worthy of consideration Crossing may also be employed to capitalize on improved maternal ability, which would be quite useful where the young suckle their dam

Unless the environment is improved to meet the needs of larger and potentially more productive animals, crossing will fail to yield the desired results Often such improvement is not economically feasible And the expected performance of local stocks may be too low to encourage development of commercial livestock enterprises The resulting dilemma is whether to try to modify the local environment and utilize an improved strain of stock, or to try to gradually improve local stocks through selection Certainly there is no universal solution

Some animal breeders contend that stocks indigenous to the tropics have great genetic variance, and that therefore quick improvement should be possible through selection On the other hand, Mahadevan (1965) concluded from a study of Nganda cattle in Uganda that although some genetic progress had been made after 12 years of selective breeding, it had not been possible to find even one outstanding bull, nor had it been possible to bring about a significant increase in milk production by selection of cows in the herd The majority of animal breeders working with indigenous cattle currently hold the view that a policy of breeding up indigenous stock will fail to yield satisfactory results primarily because of the limited resources that can or will be mobilized to provide sufficient numbers of animals and performance records for effective selective breeding

Thus it seems that some crossing of local stocks with an improver breed is warranted One cross, or the 50% level of an improved breed, will often be all that can be tolerated, at least until there is marked improvement in the environment If crossing beyond this level transpires, the program may fail, necessitating continuation of the new stock by immediate inter se mating—that is, interbreeding of the first generation crosses This approach has been reasonably well accepted in development of new strains of poultry, sheep, and swine, but there has been considerable stigma against it in cattle breeding because of the expected wide segregation of genes, which would cause the variation in the F_2 to be considerably greater than in the F_1 Increased variation in the F_2 over the F_1 would be expected when the difference between the parent stocks is large, when the number of genes involved is small, and when the heritability is high, but for characters expressed from a large number of genes, there should be little or no increase in variation in the F_2 over the F_1, irrespective of the magnitude of the difference in the parent stocks

There is little information on the expected performance of interbreeding of crossbreds in warm climates beyond that of the new strains described earlier. This is because inter se breeding among crossbreds has never been carried out for a sufficient number of generations and with enough animals to give it a fair trial. Some early investigations in India indicated a considerable decline in the performance of F_2 and later generations of inter-mated crossbreds. These results were no doubt influenced by an increase in the degree of inbreeding in the small herd. In contrast, Kidder *et al.* (1964) reported that offspring resulting from mating crossbred bulls to crossbred cows showed some advantage over purebreds at weaning, but by 12 months of age they were intermediate in weight between the parent breeds of Brahman and Devon—212, 207, and 224 kg, respectively. F_2 crosses of Red Sindhi and Jersey were 10–15% below F_1 crosses in growth rate and milk yield, which was about the level of heterosis for the F_1. The F_2 crosses were, however, 57% higher in performance than 7/8 Red Sindhi crosses (Branton *et al.*, 1966). This made the F_2 crosses about equal to the mean of the parents. Similarly, in sheep F_2 crosses have equalled the average of the parent breeds in performance (Bowman, 1966).

If it can be anticipated that the F_2 crosses will perform at an intermediate level to F_1 crosses, it would be a wiser policy to intermate crossbreds of the breed combinations that could probably be supported by the environment. The mating of crossbreds in no way changes the need for careful selection and restriction of inbreeding. Its most important advantage is that it can create in one generation a plateau of performance equivalent to that produced by several generations of selective breeding in indigenous stocks (unless at least 60% of the indigenous stock can be discarded at one time.) From this plateau, selection can begin. Cattle breeders could close their herd after one or two gradings to improved breeds and use as few as four unrelated bulls without risking severe inbreeding effects (Warwick, 1960).

METHODS OF EMPLOYING LIVESTOCK IMPROVEMENT PROGRAMS

With the foregoing observations in mind, the next step is to consider some means whereby breeding programs may be implemented. Recommendations are based on the premise that for any system to be effective some governmental participation will be required—especially in guidance of programs and provision of capital. This is not to

imply emphasis on development by the private sector but the major reasons governments must become involved is lack of the infrastructure for guiding programs, such as breed societies, and providing capital

In numerous countries, individual breeders have initiated successful programs of genetic improvement They have not, however, been as judicious in consideration of their peers resulting oftentimes in dispersion of rather inferior stocks Individual breeders frequently emphasize traits that may or may not be of the highest economic significance or contribute to the improvement in the general population Furthermore, for a program to be effective it should be closely allied to a research program, which is another important reason for involvement of government agencies and universities

The simplest and least expensive system would be for the government or its agencies to initiate a recording system whereby representatives would go periodically to the village or individual farm and measure milk yield, in the case of dairy production, or weigh calves or lambs as a means of identifying females giving the best performance The better producing females identified through these records would be earmarked so that their sons would be saved The sons would be brought to a central location and reared in a common environment, where information could be obtained on rate of growth and development for use in making further selections among the males Males selected from these groups could then be redistributed for natural service or artificial breeding (AI) for use among the general population of females This system is illustrated in Figure 10 13 The plan shows that the procedure would be repeated periodically, preferably on an annual basis, with the intent of genetic improvement This would give primary emphasis to the use of superior dams If used for milk yield in cattle, it would permit up to 33% of the total opportunity for genetic gain (Robertson and Rendel, 1950) In later years the rate of genetic improvement could be enhanced by progeny test information becoming available on the sires distributed in earlier years

A second system, illustrated in Figure 10 14, provides for establishment of a breeding research institute as a seedstock herd or flock under intensive selection Selected males could be distributed according to the previous plan for use among the general population This procedure has often been applied but without very satisfactory results The inadequacy has resulted from too few animals and too low selection differentials, mainly because the institute confined its base population to an original group of animals chosen principally on a phenotypic basis in one period of the year The males, and in-

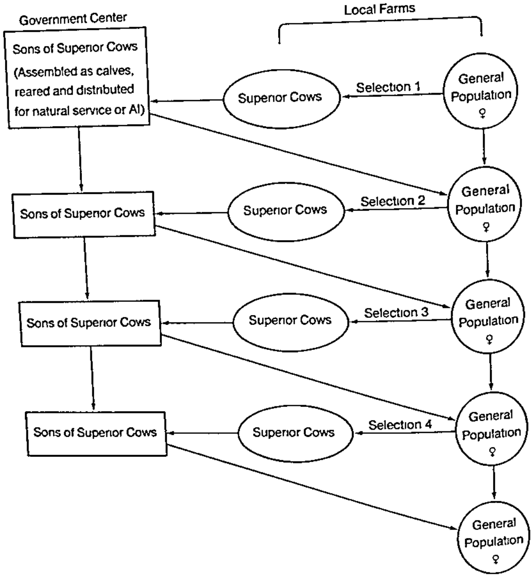


FIGURE 10.13
Plan for selective improvement in indigenous stock emphasizing selection of superior dams from among village owners for producing bulls

directly the females, selected in this rather inefficient fashion have a large influence on later generations. This system could be effective if a selected herd or flock represented the upper 30% of the general population. A more efficient system would be to select a group of animals from the general population and assemble them at the research institute or possibly a commercial farm, where they could be observed through one production cycle—e.g., lactation or lambing. Following the first "production period," 50% or more of the females should be discarded. The procedure of female selection should be re-

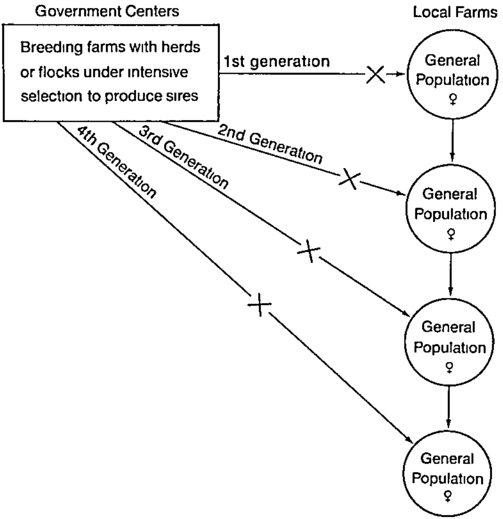
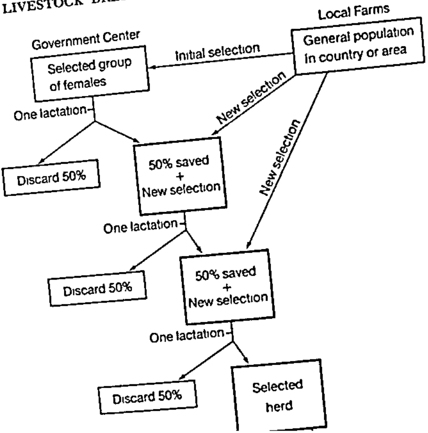


FIGURE 10 14
Plan for grading up local stock via a seedstock herd

peated for several years—at least three and preferably five. The "select" herd could be developed as illustrated in Figure 10.15. If the selection differential after arrival in the seedstock herd is 50% or higher, the basic group will be of much higher quality than a group produced by one selection period. This is not an expensive procedure as rental or condition of sale could be a part of the arrangement with the initial owners.

A third approach (Figure 10.16) is commonly practiced in many tropical areas, frequently with disappointing results. This involves the importation of sires, semen, or even groups of males and females, which are employed in a grading up scheme on local stocks. The major disadvantage as normally applied has been the small numbers of animals or semen imported. Nevertheless, this system has met with marked success in Israel and with reasonable success elsewhere. In this system the local stock is gradually replaced, but unless the environment is good the first generation cross may be the only group that performs satisfactorily. Disappointing later generations may result


Government Center
Local Farms
Selected group of females
Initial selection
General population in country or area
One lactation
New selection
New selection
Discard 50%
50% saved + New selection
One lactation
Discard 50%
50% saved + New selection
One lactation
Discard 50%
Selected herd

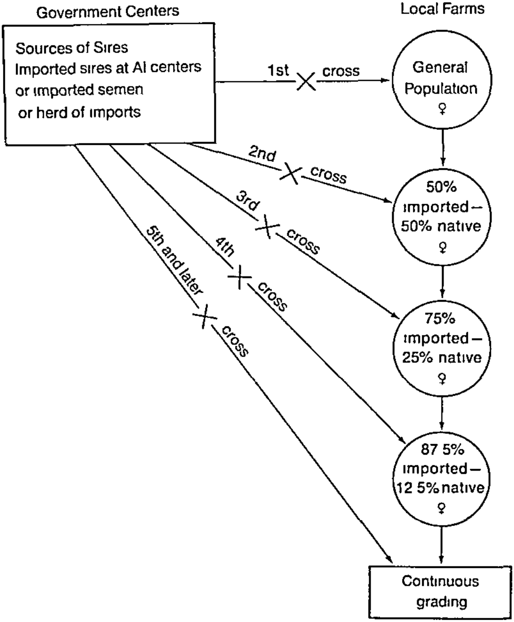


FIGURE 10 16
Plan for grading up local stock with imported stock through importation of sires, or semen, or from seedstock herd of imports

and 75% of its native breeding. In subsequent generations, the infusions of imported stock would be 12 and 6%, respectively. Grading up could proceed for 4 to 5 generations before approaching the 50% level. By the time this stage is reached, either the stocks and managers should be good enough to go on with the scheme or the managers hould be encouraged to take up some other type of enterprise. This ystem also has the advantage that if anywhere along the way part of ie producers are capable of handling better quality stock, a direct ross can be made with the imported types. It also has flexibility and ffords an opportunity to broaden the sampling of combinations of 'nported and local types.

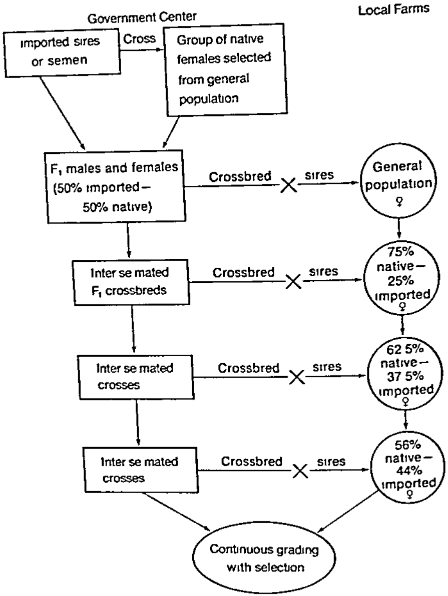


FIGURE 10.17
Plan for grading up local stock with crossbred sires produced from seedstock herds

The plans described by no means represent all the possibilities. They are set forth to illustrate some possible systems, along with their basic requirements and advantages. Two other approaches not considered are to continue the status quo or replace the indigenous stock outright by importations. Costs for the latter—on any sizable scale—are prohibitive. There will be areas, such as the Llanos region of Venezuela and Colombia, where it is inadvisable to go to the ex-

pense of introducing improved sires until the cattle are brought under higher intensity of management. Accordingly, it would be inadvisable to invest much in attempts at upgrading until large areas can be incorporated into a scheme. Whichever approach is taken, it must be kept in mind that livestock improvement is a slow, tedious, costly undertaking with many pitfalls. Although much more research is needed, there is currently adequate technology to apply certain broad principles. But these ought to be applied with more caution and systematic planning than have usually been demonstrated heretofore.

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V

MANAGING THE LIVESTOCK ENTERPRISE

11

The Functions of Management in Livestock Production

Dictionaries give a number of definitions of management, including "to operate, handling, making use of, direction, carefulness, prudence, husbandry, and decision making." The manager or person in charge of a livestock enterprise is commonly thought of as a doer or operator who executes in varying degrees all the definitions listed. But undoubtedly his most important function is that of "decision making." This is the basic role no matter what the level of the enterprise: (1) deciding what is wanted and (2) deciding how the goal is to be achieved.

What the decision maker or manager wants is concerned with the type or types of enterprises—whether it be a breeding establishment to produce animals to sell to other producers, or a commercial herd or flock to produce animal products for profit, whether an intensive, semi-intensive, or extensive operation, etc. In this context a significant part of management consists of trying to determine what results are desired. Even though professionally trained animal technicians can advise the manager on general considerations, it rests with the manager to make the final decisions for his particular enterprise. After determining his objectives, the manager must then decide

how to accomplish them. For example, he must decide what breeding system to employ and how to ameliorate the natural environment, provided the odds are reasonably good for achieving a profit.

The preceding chapters have dealt with some of the guidelines that a manager might employ, or an animal technician might pass on to a livestockman, relative to step (1) in decision making. This chapter and the other three chapters in this section, together with Chapter 19, deal with guidelines for step (2), that is, getting the desired results.

MANAGEMENT SYSTEMS

Various classifications of farm operations have been proposed. One classification is based on the intensity of the operation—intensive, semi-intensive, extensive, or nomadic. This assumes that level of intensity will determine the level of skills required by the operator and the capital investment per animal (FAO, 1968). Another method of classification is based on climatic regions, such as described in Chapter 6—namely, wet tropics, humid summer (7–9½ months rainfall), wet-dry (4½–7 months rainfall), dry (2–4½ months rainfall), and semi-desert or desert. The underlying premise is that variations among these regions will largely determine the appropriate methods of management. Others have stated that the degree of sophistication of husbandry or management practices is closely associated with systems of land tenure—e.g., large ownership versus small holdings; the availability of transportation; proximity to market or market conditions; or literacy level of the people involved. It has also been proposed that livestock enterprises fall into one of two types—"scavenger" versus productive or "livestock keepers" in contrast to productive units with the assumption that management level is low or nil for the scavenger but skills in decision making are required in a productive enterprise.

Obviously all of these classifications have some justification and numerous illustrations could be set forth to show the correlations of these to practical applications of certain practices but probably the single factor which governs whether a certain management practice is employed is its economic feasibility. The factors that determine the most feasible method of management are so numerous that any broad system of classification will prove too rigid. Each management regime must deal with its particular set of problems and also remain highly flexible.

PROBLEMS OF INITIATING MANAGEMENT PROGRAMS

Management programs have developed very slowly for a number of reasons Among these are the lack of trained personnel and the inadequacy of knowledge on which to base recommendations to farmers Trained scientists seem less attracted to research directed toward methodology in management than to research in the more specialized fields, such as nutrition and the handling of semen

Few agricultural universities in the warm climates have as yet developed undergraduate curriculum in Animal Husbandry in the context applied in universities in the north latitudes, that is as an identified area of specialization In most universities of the warm climates some courses on animal husbandry are offered as specialties in veterinary science or agronomy And many times the student has no practical experience in a livestock enterprise prior to college This means that the graduates frequently lack the requisites of practical experience to interpret technology into useful management practices for local farmers

It often involves much more work to put across changes in management practices to farmers than to put across programs such as artificial insemination or control of epizootic diseases These programs are generally executed directly through personnel supported by a governmental agency, and thus require little participation on the part of farmers In contrast, the farmer is essentially the "doer" in employing recommendations on management If he has been a pure agriculturist or a former urban dweller, the skills required for good animal management may be unfamiliar to him And even if the farmer has had long experience with livestock, a change in management that requires modification of a traditional method, such as milking a cow without the calf present, may be accepted slowly Low literacy levels and farmers' distrust of the personnel offering advice, because of association with another strata of society, are additional inhibitors

Still another factor is that attempts are made to sell management practices on a piecemeal basis instead of as a "package of practices" Frequently a change in one aspect does not render sufficient foreseeable benefits to gain acceptance (Chapter 19) But a whole group of practices may require more capital resources than are available

As attempts are made to mount programs directed toward promoting increased skills in management, it should be kept in mind that speed of acceptance will be governed by (1) the cost and risk, (2) the degree of complexity, (3) the time lapse before visible results

are evident, (4) the creditability of the persons suggesting the change, (5) the form of communication employed, (6) the timing of the approach in relation to the farmer's situation, (7) the compatibility of the recommended practice with existing methods, and (8) the degree of participation by the farmer. (See Chapter 19 for further discussion on these points.)

An additional aspect of the initiation of management programs is assistance in training labor for "multi-manned" enterprises. Often those with some experience in handling livestock use traditional techniques unsuited to highly productive operations—e.g., hobbling the rear legs of a cow in a modern milking parlor.

IMPROVED MANAGEMENT THROUGH INTENSIFICATION OF LABOR

To the outsider, enterprises with very low output per unit of land or animal unit seem to be in need of more labor. He assumes that if more attention were given to the stock and to other aspects of the operation, such as control of weeds in the grazing lands, the efficiency of the operation would be improved. This is not always the case. In some instances intensification of labor will give little or no recognizable benefit. But in others it may increase returns dramatically.

For example, in Colombia a survey revealed that losses in potential productivity in cattle herds were mainly attributable to poor reproductive performance (50% calving rate per annum), death losses from birth to weaning (15%), mortality from weaning to market age (5%), and losses from poor growth (30%). Since most of the losses seemed due to lack of close attention to the animals, several large haciendas were chosen for training of workers in methods of heat detection, treatment of minor health problems, and care in handling of cattle. After one year the average calving rate for these haciendas was raised from 40 to 65% and death losses from birth to weaning were reduced from a previous level of 25% to 5%. The estimated number of man hours per animal was increased about one-third. Hence a very high return was realized from increased labor and, particularly, from improvement in the skills of labor. Equally spectacular results were obtained through a similar program on a sheep enterprise with 1500 head (Pino, 1968).

It is a well established fact that close attention to animals will give some returns. Increased labor intensity will almost certainly aid in improvement of reproductive efficiency and viability. The same recommendation could be applied to reduction of health problems

with some materials available, such as a disinfectant. Often significant returns are also realized from increased labor intensity in the management of feed supplies. The use of rotational, rather than continuous, grazing represents an example. Still, there are situations where increased labor intensity will not yield acceptable benefits. Such is the case where animals are grazing over very large areas. Because of the extensiveness of these operations and distance from the market, the costs of operating these enterprises must be minimized, primarily by having a large number of animals per man. To double or triple the man hours of attention given the herd or flock would no doubt aid in reduction of animal losses but would not be warranted on an economic basis under existing marketing conditions.

Probably the most abused concept about the benefits of increased labor intensity pertains to nomadic herding and small farms. The conventional concept is that if the enterprises expanded labor inputs, their returns from livestock would be materially enhanced. Careful study of practices employed by these people reveals serious doubts as to the validity of the recommendation. Both the nomadic herder and small farmer give close attention to females at time of parturition. Although they have had no formal training in animal husbandry, they commonly follow the practice of assisting in difficult parturitions, drying of the young to prevent chilling, seeing that the young suckle one or more times, treating wounds and removing ticks. These people are equally aware of the need for attention to their animals in other stages of life. But because they give primary emphasis to family needs for milk supplies, either for direct use or for sale, instead of rearing all stock born for later use or sale, the mortality rate of young animals is high. If the losses of animals in the nomadic herds are largely from malnutrition or epizootic diseases, increased labor intensity will have little or no effect. The same is generally true for small farms.

It is frequently recommended that the small farmer plant an additional crop to enhance feed supplies for livestock. The inference is that this may transpire largely through more labor inputs on the part of the operator and his family. Such a recommendation is not widely accepted for several reasons, one being that the capital investment required for the needed seed is beyond his resources. No doubt of equal or greater significance is the labor requirements in relation to availability for harvesting the cereal grain crop prior to planting the forage crop. The harvesting process for the main crop is laborious and time consuming, so by the time the farmer can devote time to land preparation and seeding, the season has advanced to the point where there is low probability of a successful crop. This is frequently the case in countries such as India.

Although increased labor intensity *per se* will sometimes yield significant benefits, it cannot be recommended as a general practice. Where livestock productivity is lowest, it is probably the least significant. On the other hand, when capital investment per animal is increased, more inputs of labor may be mandatory otherwise all will be lost. If, for example, a nomadic herder adds a ram of an European breed, such as Rambouillet or a Rambouillet-Native crossbred, to his flock but does not give the new ram attention until it is adjusted to flock environment, the ram may be lost in a short time. Another example would be when a livestockman starts a tick control program that requires dipping of the cattle on a regular schedule. More labor will be required for the dipping operation but unless the schedule is adhered to the animals may become more susceptible to the disease transmitted by the tick, leading eventually to higher losses instead of the desired results.

AN APPROACH TO DEVELOPMENT OF A MANAGEMENT PROGRAM

Figure 11.1 suggests a realistic approach to determining the measures that will enhance the efficiency of livestock production in the warm climates. (The ratio of energy input to milk output is the same as that for Figure 4.5). The available feed energy is ordinarily the primary limiting factor that permits other forces to become inhibitors. The hatched area in the lower corner of the graph shows the minimum amount of feed energy (Mcal)—not kilograms of feed—required annually to sustain an indigenous (Z) cow with a body weight of 275–300 kg. This serious limitation on feed might be classed as a "survival" type environment, meaning that under these circumstances small breeds of cattle would gradually reach maturity and eventually manage to produce sufficient offspring to just about replace themselves; whereas, perhaps crossbreds and surely pure European breeds would not survive. In several respects this is an inefficient system as four to five times more feed energy are required to produce a unit of animal product than if the nutritional level is higher. If the level of energy is increased, the performance of the individual will improve but the inputs of energy will reach a point of diminishing returns because of other factors aggravated by the climatic conditions or genetic potential. The next inhibitors of performance are usually disease and parasites. The extent of the effects will vary among locations but effective control measures are important in the efficient utilization of feed (Chapter 13). If measures are taken to control disease, high re-

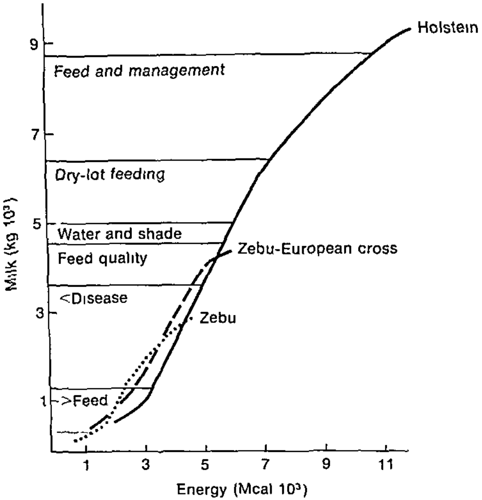

FIGURE 11.1
Environmental variables that may influence the ratio of milk yield to energy intake for three types of cattle—Zebus, Zebu-European crossbred and Holsteins (From McDowell, 1967, Fig 6, p. 287 Ground Level Climatology, Pub No 86 Copyright 1967 by the American Association for the Advancement of Science)

turns may be expected from increased inputs of feed energy. Because the feedstuffs ordinarily available in warm climates are of low quality during much of the year, it may often be practical to apply inputs to enhance both quantity and quality (e.g., improved grasses). If the extreme fluctuations in feed quality and quantity are alleviated by using partly stored feed supplies, this brings the animals into partial confinement where provisions for some shelter and better water supplies would aid in efficiency of performance. These steps ought also to help ameliorate the direct effect of a hot climate. The area between the 6300 and 8600 kg lines, labeled "Feed and Mgt.," represents a number of additional techniques of husbandry that may be applied, such as zero pasture, frequent feeding (up to six times per day), and the use of green chopped forages along with stored forages.

Figure 11.1 also distinctly illustrates how the level of affordable

inputs influences the choice of animal genotype. It would be unwise to choose other than a small type of animal when the energy value of the feed resources is equivalent to no more than 1500–2000 Mcal per year. On the other hand, if it is possible to mobilize feed supplies exceeding 4000 Mcal per animal annually, the small animal would probably not make the best use of the feed without gross genetic change.

Obviously, some changes in the environment are necessary to improve livestock production in the warm climates. The discussions in the following three chapters deal with some of the measures that the manager of a livestock enterprise may employ to minimize inefficiencies in animal performance relative to reproduction, animal health, and resources such as feed supplies and shelters. Since few recommendations are applicable to all situations, a number of experiences that have proven successful in improving efficiency are used as illustrations. The decisions as to usefulness for a given situation are left to the discretion of the reader.

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12

Management in Relation to Reproductive Performance

Reproductive inefficiency is probably the largest single cause of loss in livestock production. Functional sterility accounts for 30–40% of the disposals of females from dairy herds and 50–55% of the disposals from beef herds in the U.S. (Table 12.1). If the optimum reproduction rate for cattle is defined as the production of the first offspring at 2 to 3 years of age and subsequent offspring at 12-month or shorter intervals, sub-optimal performance is a worldwide problem. And the problem is particularly serious in the warm climate region.

In Canada it is estimated that the national average calf crop from cows of breeding age is 75–85% in beef herds and 66–72% in dairy herds. In Denmark the conception rate for all cows in dairy herds during recent years has consistently exceeded 90%, with an average of 1.68 inseminations per conception. Dairy herds in Britain, West Germany, and New Zealand report 93, 87, and 86% annual conception rates, respectively. The average calf crop (proportion of calves alive at birth) for beef herds in the southern U.S. is estimated at between 65 and 70%, with dairy herds averaging about 85%.

In warm climates of low rainfall, calf crops of 45–55% are average or above average. Calving at 18-month intervals or longer is the rule.

TABLE 12 1
Major reasons for disposals of females in commercial and experimental beef and dairy herds in the southern United States

Cause	*% in dairy herds*		*% in beef herds*	
	Comm	*Exp*	*Comm*	*Exp*
Sterility				
Nonbreeder	24	35	48	44
Abortion	5	4	8	6
Physical injury	3	5	7	5
Mastitis	15	14	3	3
Death	5	6	8	7
Poor performance	17	11	8	10
Other	31	25	18	25

Calf crops of 40–50% are common in the tropical and subtropical portions of Australia Frequently in Latin America annual calf crops in beef herds are 30–50%, with well managed herds ranging up to 75–80% if the bulls remain in the herd during the entire year The annual calving rate for Central Africa has been estimated at 30–40% although some herds, particularly at government stations, report calving rates well above 70%

From these data it can be concluded that the average annual calving rate for most of the world is lower than desired for optimum efficiency However, there are definite possibilities for improvement through enlightened management and disease control The livestock manager has two basic alternatives for improving reproductive performance in his herd manipulating the breeding system for genetic change, or reducing the impact of environmental influences

MEASURES OF REPRODUCTIVE EFFICIENCY

Reproduction efficiency as applied to herd or flock management has no specific definition Normally it is measured as a deviation from some standard created by man for his livestock using time as the bench mark When females do not conform or fall short of the established expectancy, they are removed from the herd or flock On this basis a more appropriate expression would be "reproductive inefficiency" For cattle, some of the standard measures of reproductive function are (1) services per conception, (2) length of service period, (3) days open, (4) calving interval, (5) non-return rate, and as indicated

above (6) calving rate or calf crop. Even though all of these measures indicate reproductive performance, two or more are usually required to identify causes of slippage from the predetermined standard.

The ideal number of services per conception would be 1 per pregnancy. Well managed herds have an average of 1.3–1.6 services per conception, because of inappropriate time of breeding or other causes, while the majority of poorly managed herds have an average of 2 or more services per conception. In the latter, managerial practices should be examined, taking into consideration the factors discussed in Chapters 12–14.

Length of service period is defined as the time span from first breeding until conception (date of conception minus date of first breeding). Long periods—exceeding 30 days—point up problems of too many services, inadequate detection of estrus, possible uterine infections, or embryonic mortality. Service period is easily determined when AI service or "marker males" (usually vasectomised male or intact male with harness carrying material for marking female when mounted) are used, but it is difficult to obtain with any degree of accuracy otherwise.

Days open is a term employed to describe the period from parturition to conception (date of conception minus date of previous parturition). Although this measure does not identify cause(s), it provides a means of evaluating the economic consequences of reproductive inefficiency. For instance, in well managed beef herds it is accepted practice to cull cows when they are found not pregnant at the end of the breeding season because they have exceeded the tolerance of 150–160 days open. This practice is based on the owner's experience that it is not profitable to hold females over for more than a year without return. In U.S. dairy herds a cow not pregnant by 200 days after parturition has less than a 50% chance of being held for a subsequent lactation even though she may conceive before lactation ceases or within 10 months after calving. This is because it has been found that cows open 86–116 days after calving will show a decreased return of \$0.50 for each day open during that period, compared to cows settled on or before 85 days. The decrease in return will rise to \$0.78 per day if conception was delayed for 117 days or longer after parturition (Speicher and Meadows, 1967).

In many respects calving interval is the measure of most interest to the livestockman since it has a marked effect on consistency of herd or flock yields, decisions on culling, number of herd replacements, planning of feed supplies, and determination of labor needs. It has the advantage of being easily determined but a disadvantage is that it does not identify deficiencies in management except in a gross fash-

TABLE 12.2
Influence of calving interval and length of productive herd life on number of lactations completed and estimated total income over feed cost per cow

Herd life[a] (years)	Calving interval (days)					
	385	400	430	450	480	520
	NUMBER OF LACTATIONS COMPLETED PER COW					
2.5	2.4	2.3	2.1	2.0	1.9	1.8
3.0	2.8	2.7	2.5	2.4	2.3	2.1
3.5	3.3	3.2	3.0	2.8	2.7	2.4
4.0	3.8	3.7	3.4	3.2	3.0	2.8
4.5	4.3	4.1	3.8	3.6	3.4	3.2
	TOTAL INCOME OVER FEED COSTS PER COW ($US)[b]					
2.5	592	570	530	500	475	450
3.0	711	684	637	637	570	525
3.5	830	800	743	743	666	600
4.0	948	913	850	850	760	700
4.5	1075	1028	955	955	855	800

[a] Time from first calving until animal leaves the herd
[b] The average yield per lactation of 3632 kg would give a $250 return over feed cost which does not include cost of dry cow maintenance

ion. Nevertheless animal husbandry technicians can use it effectively in demonstrating the economic consequences of long calving intervals.

The value of recording calving intervals is demonstrated by the following examples: In Table 12.2 are illustrated the variations in expected number of lactations completed by cows in their life time if calving interval varied from 385 to 520 days. If a cow remained in the herd 3.0 years and had an average calving interval of 385 days, she would be expected to complete slightly over 2.8 lactations, but only 2.4 lactations when calving interval was 450 days. The values in the lower portion of the table portray the influence of length of herd life and calving interval on life time returns over feed costs. These values do not allow for feed costs during the dry period, however. If a cow completed 2.84 lactations of 280 days duration in 3 years, her total returns over feed costs would be $711.00, based on $250.00 per lactation. Her total number of days dry would be 261. When these are charged at $0.50 per day, the net return over feed costs would be $581.00 instead of $711.00. On the other hand, a cow completing only 2.4 lactations in 3.0 years would have about 400 dry days. This would make her net return over feed costs only about $400.00, or approximately 30% less than if she had calved at intervals of 385 days. If the

purchase or rearing costs of the latter cow were $400.00, all charges for labor and capital investments would have to be realized from her salvage value.

Another example of the magnitude of the impact of calving interval on farm returns comes from experiences in Puerto Rico. Caro-Costas and Vicente-Chandler (1969) estimated, from experiments, that the cost per year for keeping a dairy cow on a farm using an all-pasture feeding program would be $300.00. Since there was no feed purchased, the overhead cost per cow was essentially the same whether she was dry or lactating. When the all-pasture program was put into practice on farms, the returns per year for a herd of 120 lactating age cows were only $6,450.00. This was 91% lower than the expected returns of over $12,000.00, mainly because the average calving interval actually occurring on the farms was 430 days instead of 380 days, as in the experiments (Table 12.3). The very low returns on

TABLE 12.3
Estimated returns from 50 hectare dairy operation in hill region of Puerto Rico with all-grass grazing program, average herd life of 4 years, and average calving intervals of 380 or 430 days[a]

Item	Calving interval (days)	
	380	430
Number of lactations completed/cow	3 8	3 4
Number of calves produced for sale	3	3
COSTS FOR HERD LIFE OF COW (US)		
Direct cost/cow for lifetime ($300/yr)[b]	1200 00	1200 00
Purchase price/cow	500 00	500 00
Total costs/cow for herd life of 4 years	1700 00	1700 00
RETURNS ($US)		
Sale of calves @ $25 00	75 00	75 00
Salvage value/cow[c]	180 00	180 00
Sale of milk (2713 kg/lactation, $0 18/kg)	1856 00	1660 00
Total returns/cow for lifetime	2111 00	1915 00
Net return/cow[d]	411 00	215 00
Return/cow/yr	102 75	53 75
Net return for 120 cow herd/yr	12,330 00	6,450 00

[a] Entire farm is devoted to lactating herd at 2.4 cows per hectare, therefore, costs for labor, feed, and interests are constant for dry and lactating cow

[b] Prorated costs for labor, fertilizer, veterinary care, AI service, transportation, taxes, insurance, interest on facilities and cattle, and depreciation

[c] Average sale value of culled cows for meat.

[d] Net return/cow = average total returns per cow for lifetime minus total costs per cow for herd life of 4 years

the high investment was not effective on farms because of the failure on the part of farmers to be as conscious of breeding efficiency as the experiment station

Non-return rate is generally expressed as the proportion of females that have not shown repeat estrus within a certain time span after being serviced—usually 60 or 90 days It is most widely used by AI organizations to estimate breeding efficiency among the sires in service and to keep track of the quality of work among inseminators Non-return rate serves the same purposes for the farmer

Calving rate or calf crop is more frequently used in semi-intensive or extensive operations than in dairy herds The normal procedure is to identify the number of females that have produced one or more offspring within a year's time This measure, too, is closely related to expected economic returns as well as to decisions on culling and herd replacements

The dairy enterprise that has invested in building and equipment should give primary consideration to keeping a complete record of reproduction on each female, including the factors listed as well as reproductive disorders and condition of offspring If this is not possible, an alternative would be to record all dates of parturition, estrus, and breedings From either set of records levels of efficiency and the most likely causes of poor reproduction could be identified In extensive operations, with no controlled season of breeding, annual counts of calves and check of reproductive tracts are desirable The second choice in these herds would be cow identification with annual record of evidence of calving

The main concern in the following sections will be with identification of causes of reproductive inefficiency and means of improvement in rebreeding within a reasonable period, rather than problems of complete sterility, since all but about 5% of females will eventually conceive

CAUSES OF REPRODUCTIVE INEFFICIENCY

Reproduction rate and/or fertility of livestock are complex phenomena Consequently, reproductive efficiency must be viewed as a phenotypic expression of the interplay of genetic and environmental factors Genetic factors include both single gene and polygenic effects as well as effects due to breed and system of breeding, such as crossbreeding and inbreeding Environmental factors consist of management (detection of estrus, number of males per 100 females,

nursing of young, movement of animals, and age of animals), nutrition (energy, protein, minerals and vitamins, and feed additives), diseases and parasites (genital diseases, somatic diseases, repeat breeding, anestrus, other endocrine disturbances, and internal and external parasites), and season of the year. In addition there are genetic-environmental interaction effects on reproductive efficiency.

Genetic Influences

Anatomical and Physiological Defects

As pointed out in the discussion on breeding, it is generally accepted among animal geneticists that the heritability of reproductive efficiency is rather low. Among temperate zone cattle the heritability for nonreturn rate ranges from −4% to +8%; services per conception −15% to +8%; first service to conception +1% to 9%; and calving interval 0 to 10% (Foote, 1970). These statistics suggest that any progress by selection will be slow. Nevertheless, there are at least 14 reproductive anomalies, mostly of a morphological nature, which have been identified as having a genetic basis. Most of them have been interpreted as being controlled by a single pair of alleles (Tanabe and Almquist, 1967). These anomalies include (1) hypoplasia of the genital ducts or gonads, (2) intersexuality or sexual imperfection (freemartin), (3) defective gamete formation—e.g., abnormal sperm, (4) embryo anomalies, (5) lethals resulting in nonreproducing offspring, and (6) other functional defects—e.g., lack of libido, silent or weak estrus, or cystic ovaries.

Gonadal hypoplasia (under-developed sex organs) has been observed occasionally in males of most breeds of farm livestock. It became a very acute problem in Swedish Highland cattle at one time, with up to 30% males affected. Nearly a century ago "white heifer disease"—a hypoplasia confined to the uterus, cervix, and anterior vagina—was noted in Shorthorn heifers. A similar condition has been observed more recently among Nguni (Shorthorned Zebu) in South Africa. Infertility (about 20%) in horned male goats in Germany has been attributed to testicular lesions, a form of hypoplasia. These are only a few examples, varying degrees of hypoplasia occur in all species, with females more frequently affected than males.

Numerous studies with bulls have revealed various morphological abnormalities in sperm, which appear heritable (Foote, 1970). It may be that oocytes stored in the ovary of the female have similar defects, but because female gametes are very difficult to obtain, few

facts are known The period of early embryonic development is a common stage for reproductive failure, but the extent to which heredity is involved is unclear

As pointed out in Chapter 9, there are numerous lethals that occur with varying frequencies in different species of livestock When these occur in the homozygote state, as in dwarfism, the general fitness of the animal is impaired, which in turn reduces reproductive efficiency The effect of lethals is largely indirect as they do not normally act directly on the reproductive system (Nat'l Acad Sci , 1968)

There is some evidence that frequency of stillbirths is influenced by heredity, the percentage of stillborn calves may be as high as 16% in some breeds and near zero in others in nearly similar environments But the findings are blurred somewhat by the different definitions of stillbirth Some researchers have used the number of foetuses obviously dead before the onset of parturition, whereas others have included in their data all young that did not live for several hours or 1–3 days

Dystocia (difficult parturition) may also have a marked influence on the number of calves born dead In severe cases, both the dam and offspring may die or there may be subsequent sterility due to traumatization of the reproductive tract or infection In a crossbreeding program in Britain, Friesian, Ayrshire, and Hereford cows had a much higher incidence of dystocia when bred to Charolais bulls than when bred to sires of their own breeds In the U S , purebred Brown Swiss had twice the frequency of dystocia as pure Ayrshires and Holsteins When Brown Swiss sires were mated to Ayrshire and Holstein cows there were 5% fewer calves born alive than when Brown Swiss sires were not used (McDowell and McDaniel, 1968) It is well recognized that there is also an effect of parity on the frequency of dystocia In well managed herds of European breeds the incidence is about 20% at first parity but decreases to about 5% in later parities If heifers are grossly undersize at first parturition the incidence may well exceed 50% This is the main reason for the widely accepted practice of breeding for first parturition to males of smaller breeds than those of the females Estimates from field surveys in Venezuela, Costa Rica, Puerto Rico, Chile, and Mexico have shown that over 70% of the dairy heifers, largely of high-grade European breeding, are bred to Zebu or Criollo bulls for first pregnancy to minimize problems of difficult calving

There is some evidence that the frequency of nymphomania, tendency for cystic ovaries, retained placenta, intensity of expression of estrus, and time of estrus after conception are genetically inherited Casida and Chapman (1951) gave an estimated heritability of occur-

rence of cystic ovaries in one herd of Holsteins as 43%, although most estimates range from 5 to 15%. Even though estimates of inheritance for cystic ovaries, nymphomania, etc. may be fairly high on small samples, it appears that the occurrence of these conditions is more related to individual sires or families than to cattle populations as a whole (Lagerlof, 1962).

In some breeds of cattle, such as the Santa Gertrudis, males may have an extra large sheath, resulting in prolapse of the prepuce that impairs natural breeding. Although circumcision can overcome this condition, bulls showing large sheaths should be avoided in this breed, if they are to run on pastures covered with brush or tall, coarse grasses. Furthermore, it has been observed that bulls with large pendulous sheaths frequently have poor libido, are sluggish in serving, and tend to produce low quality semen.

The recorded evidence for anatomical defects of the reproductive system stems largely from studies of temperate zone cattle, but it seems reasonable to suspect similar frequency among stocks indigenous to warm climates. Managers must be on the lookout for anomalies that may impair reproductive efficiency. Of course, those which create permanent or even temporary sterility are under continuous natural selection. The more severe the depression, the more intensive is the natural selection. To enhance the natural forces, managers should practice as much selection as their enterprises will permit against males and females that show evidence of anatomical or physiological defects.

Breeds and Breeding

Among European breeds of cattle used for dairying differences in reproductive efficiency are unimportant but breeds used for beef production have consistently shown poor breeding efficiency, irrespective of the environmental conditions, while others have high fertility. The Africander of South Africa, the Brahman of the U.S., and possibly the Santa Gertrudis and Shorthorn, have consistently been less efficient in reproduction than other cattle breeds maintained in the same environments. A study of six beef breeds in the southern U.S. showed that Angus and Hereford cows gave birth to and weaned higher percentages of calves than Brahman, Brangus, Santa Gertrudis, and Shorthorn cows. Brangus and Santa Gertrudis were similar in reproductive efficiency and both were higher than Shorthorns. A higher percentage of the Brangus and Santa Gertrudis cows were removed from the herds for reproductive causes than were

TABLE 12 4
Annual calving percentages for various breeds and crosses in three subtropical areas

Breed	*Calving percentage*	*Location*
Angus	83	Florida
Hereford	81	Florida
Brahman	69	Florida
European × Brahman	71	Florida
Santa Gertrudis	68	Florida
European	65	Queensland
European × Brahman F_1	72	Queensland
European × Brahman F_2	50	Queensland
European × Native	59	Rhodesia
Native	62	Rhodesia

cows of the other breeds Also, a larger percentage of wet than dry cows were removed for reproductive causes in Brangus and Santa Gertrudis groups, while in the Angus, Brahman, Hereford, and Short horn breeds, a larger percentage of dry cows were removed And the Brangus and Santa Gertrudis had a greater tendency than the other breeds toward alternate year calving (Temple, 1966)

In South West Africa, the fertility (expressed as calving percentage per year) of eleven breeds varied from 76% for Red Polls to 89% for Brown Swiss The two best breeds, based on the yield of meat per cow bred, were Simmental and Brown Swiss, followed closely by Hereford (Vorster, 1964) Table 12 4 illustrates the variation among breeds in annual calving percentages in three subtropical areas

Several breeds have a reputation for high fertility in the tropics Heifers of the Quasar, a breed evolved in Queensland, Australia, can be bred to calve as early as 25 months, with subsequent annual calving percentages of 90–95% The Boran of Kenya has consistently maintained calving percentages of 85–95% The Mangum of Rhodesia is another breed that has an average calving rate of 85% The Romosinuano and San Martinero breeds of Colombia also have calving rates of 80% or better

If calving interval is used as an expression of breeding efficiency, the Blanco Orejinegro cattle of Colombia and the Harro cattle of Ethiopia appear to be excellent, averaging less than 400 days By contrast, most Zebu breeds in India have intervals well over 400 days (Chapter 8) Based on these observations, it appears that several of the indigenous breeds of Colombia and Africa have better reproductive efficiency than Zebu stocks from India, Zebu type cattle in most of

Latin America, and Brahman cattle of the U.S. It is also evident that reproductive efficiency can be kept high if it is given close attention in the development of new strains. However, it must be cautioned that since breeding efficiency is markedly influenced by environmental factors, managers should be wary of transferring experiences directly from one location to another or in comparing one breed to another on one trait. Both the Blanco Orejinegro and Harro have very short lactations—100–170 days—as compared to 250 days or more for most other breeds, thus their poor milk yields may not offset their more rapid breeding. Furthermore, the time span of the recordings should be examined since there is considerable yearly variation in calving percentage. In beef operations, a high calving percentage one year is often followed by a low calf crop the following year, irrespective of breed. Frequently less than 50% of the cows will calve in consecutive years in the tropics, especially where there is a distinct dry season.

As indicated in the chapters on breeding, there are apparently inherent differences in breeds in the age of puberty or sexual maturity. For example, in Louisiana, Brahman females seldom will show heats until 2 years of age with first calving at about 3 years of age, whereas Angus can be bred for calving at 2 years of age (Turner and Farthing, 1967). Late puberty generally constitutes a disadvantage in overall herd reproductive efficiency. But where feed supplies are poor or the heifers are not separated from adult cows and males, it may prove an advantage up to a point. In dairy operations late maturity is generally undesirable; consequently the breeder should avoid selection of sires from families with consistently late calvers.

It was also pointed out in Chapter 10 that crossbreeding may be used to enhance reproductive efficiency in all species. The data in Table 12.5 further illustrate that crossbred cows will wean 10% or even more calves than purebreds. Donald and Russell (1968) and

TABLE 12.5
Calving and viability of calves (in percent) from purebreds and crossbreds among Angus, Herefords, and Shorthorns

Breed group	*Cows calving*	*Calves alive at 36 hours*	*Calves weaned*
Purebreds	85	79	76
Two-breed crosses	93	90	89
Three-breed crosses	89	86	84
Backcrosses	93	88	87

Source Adapted from Gaines *et al.*, 1966

McDowell *et al* (1970) also showed 10–15% advantage for crossbred dairy cattle over pure breeds in breeding efficiency A number of studies indicate that equally effective results can be obtained from crossbreeding in the tropics

Environmental Influences

Nutrition

The level of feeding at various stages of the reproductive cycle seems to have an important influence on reproductive performance, although the nature of this influence is not yet understood In fact, level of feeding and fluctuations in feed supplies probably account for the largest variations in reproductive efficiency among herds and even among individuals in the same herd of cattle or flock of sheep

Low levels of protein and energy may lengthen the interval between parturition and estrus or ovulation (Wiltbank *et al*, 1965), but it is not known if level of protein has an independent effect Usually when protein levels are low, the total intake of energy is low too In Louisiana, only 23% of cows of beef breeds were pregnant by the forty-third day of breeding on low protein grass pastures in contrast to 69% on good quality pastures In another study in Louisiana (Hall *et al*, 1959) post-conception estrus among cows on poor nutrition, including low protein, was 14%, in contrast to only 6% among cows on good nutrition

Poor nutrition during early life greatly retards the onset of puberty in cattle, sheep and buffaloes, but appears to have little effect on swine Underfeeding will delay puberty in both male and female sheep and cattle until they reach a minimum fraction of mature size Therefore, whether cattle and sheep are on high or low nutrition, they will be nearly similar in size at puberty This is not true for swine, however Boars or gilts reared on high levels of feeding are much larger at the time of puberty than similar animals fed at a low level

Level of feeding of the heifer or cow will influence the size of offspring, but in proportion to the dam's weight, the calves from low-fed females are larger than those from high fed females The same holds for young and old ewes

High feeding can also be detrimental to reproductive efficiency of females According to Reid *et al*, (1964), heifers reared on a high plane of nutrition encounter more breeding problems later in life

than heifers fed at medium or low levels. Heavy feeding of sows after mid-gestation causes serious embryonic mortality. From present evidence, it appears that medium level of feeding is to be recommended over either high or low feeding for best reproductive efficiency, especially up to the time of first parturition.

It has also been observed that females will not conceive unless they are in a gaining state. Research with cattle and sheep in Britain and Australia showed that females losing weight had low frequencies of estrus and near zero conception, those fed at maintenance levels had fair conception rates, but those gaining weight had expected frequencies of estrus and high conception rates. Evaluations of typical feeding schedules for dairy herds in Puerto Rico and Venezuela revealed that insufficient energy the first 3 months of lactation was probably the primary reason for delay in the onset of estrus. Repeat breeding was also a problem in these herds, but the cause – whether mineral deficiency, improper time of breeding, or improper semen handling – was not identified.

It has often been observed in the warm climates that high grade European type cattle or their crosses with native cattle have greater "lactation drive" than pure native types. As a result they are likely to lose more weight than native types early in lactation. Hence underfeeding will affect their reproductive rates more strongly than it will affect the rates of most indigenous stocks.

It would seem reasonable to assume that if nutritive requirements are met for growth, good health, and lactation they will also be adequate for reproduction. But this is not always true. Reproduction rates are frequently low in high producing cows, irrespective of breed, due to limitations on feed intake and, possibly, imbalances in the ration. Evaluation of feeding regimes for several dairy herds in the U.S. revealed that high producing cows in early lactation had dietary deficiencies of both energy and phosphorus. Although the energy level contributed to problems of repeat breeding, circumstantial evidence indicated that inadequate intake of phosphorus at about the time breeding was expected to commence was responsible for poor fertility (Morrow, 1970).

It has also been observed that high yielding cows continue subnormal levels of gonadotrophins for a longer period than low yielders which is probably an indirect effect of lower energy than needed. Cows milked more frequently than twice per day, those suckling calves or cows with anemia have low levels of gonadotrophin too. Other mineral and vitamin deficiencies may on occasion interfere with reproductive performance (see Chapters 6 and 14).

In Southern Rhodesia, supplementary feeding of cows in beef herds, in conjunction with early weaning of calves, has proved promising When cows were fed a small amount of high protein supplement during the dry season before parturition and up to 1 month after calving, and calves were weaned at 2–3 months of age, conception rates were 93–100%, as compared to near zero for cows without supplement and early weaning Without early weaning, cows fed supplement had a 42% conception rate (Rose *et al* , 1964)

The possibility of dairy heifers calving well under two years of age has been evaluated in Israel (Amir *et al* , 1967) Friesian heifers fed on high energy rations had their first estrus at about 177 days of age, at an average weight of 225 kg They required 3 services for conception, nevertheless, they calved from 13 5 to 17 5 months of age and yielded over 2700 kg of milk in first lactation Such practices, while not generally feasible, further illustrate the role of nutrition on age of puberty and reproductive performance

Feeding level does not affect the fertilization rate in sheep or swine In both species, a high plane of nutrition for 3 or more weeks prior to mating favors a high rate of ovulation This has led to the practice of flushing (high feeding for 2 to 4 weeks) of ewes prior to breeding However, flushing does not increase twinning or embryo survival Flushing of swine will tend to bring about an increase in litter size, but only if high feed intake does not continue into gestation, if it does, embryo mortality will be high The flushing effect is more pronounced in gilts than in sows A low plane of nutrition in both ewes and sows after mating is conducive to a high rate of embryonic mortality

Overfattening of females has caused low fertility in beef cattle, sheep, and swine, but has not proven a serious problem in dairy cattle If the females have been overfat from an early age, an underdeveloped reproductive tract may result The ovaries may be undersized and the estrus cycles irregular or absent

Figure 12 1 portrays the importance of modulation of the environmental fluctuations on the reproductive performance of cows in the warm climates Under the traditional system of feeding by grazing alone, a cow produces about 2 calves by the time she reaches 5½ years of age, but if the vacillations in body weight are reduced with supplementary feeding, the females breed earlier and are more consistent breeders The broken line in the graph shows that if cows are given supplementary feeding in the form of improved pastures before breeding and during the nursing period they will produce up to 4 calves by the time they reach 6 years of age

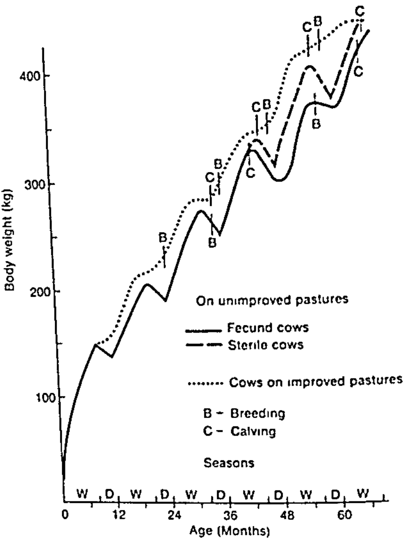

FIGURE 12.1
Growth patterns and reproductive performance of cows on unimproved versus improved tropical pastures with 7–8 month wet seasons (From McDowell, 1966)

Season

In the warm climates, the indirect effects on conception rate of rainfall distribution—through its effects on feed supply—are probably more important than the direct effects of high temperature. The high temperatures do, however, influence the frequency of estrus, as well as its intensity and duration, time of ovulation, and perhaps fertilization (see Chapter 4). Other measures, such as sheltering females from the heat during the hotter part of the day or from the night chill in semi-arid areas has proven effective in improving breeding efficiency. Brahman females sheltered during the winter months in Florida and Louisiana tended to show less post-winter anestrus.

Considerable progress has been made in increasing the prolificacy of sheep by modifying seasonal breeding activity It has been demonstrated that with a system of early weaning and rearing of lambs separate from ewes, lamb crops can be produced every 7–8 months instead of 12–18 months This procedure is probably unfeasible for large flocks on range grazing, but for smaller flocks it appears promising Rollinson *et al* (1969) concluded from studies in Iraq with Awassi sheep that limiting the use of rams to insure a concise lambing season is probably the most important single factor in improving sheep production in many countries

The average duration of estrus for ewes is about 27 hours There is some evidence that it is shorter in hot areas—possibly as short as 16 hours The average estrus cycle in temperate areas is 16–17 days and there is little indication that the cycle is significantly different in tropical areas

Numerous studies have shown that the water buffalo has a strong tendency for seasonal breeding in India, but recent evidence indicates that the seasonal effect is a quiescent stage for males and females rather than anestrus or lack of spermatogenesis (See Chapter 16)

There are seasonal variations in sexual expression of both male and female goats The volume and motility of semen are good during summer and fall but poor in winter Female goats are seasonably polyestrous in temperate areas Heat periods generally commence during late summer and autumn, but in the tropics females can breed almost any time of the year Even so, a shortening of the hours of daylight stimulates the onset of estrus and a lengthening retards it Although there is a tendency for seasonal breeding in goats in all regions, their breeding is less restricted than that of sheep

Most of the studies on length of estrous cycles in cattle indicate that seasonal fluctuations do not cause cattle to deviate very much from 90% or more of the intervals falling between 14 and 22 days For example, near Maracay, Venezuela, where the mean annual temperature is 25°C (average maximum 31°C and minimum 19°C), and there is a dry season of 6 months, the distribution of estrous cycles for Holsteins did not differ appreciably from the distribution in the temperate zone The percentages by interval were as follows

Interval (days)	*Observed estrus (%)*
<17	1 3
17–24	76 8
25–36	15 4
37–46	2 5
>46	3 8

Observation for estrus was made three times daily: 6:00 A.M., 11:00 A.M., and 6:00 P.M. Others, such as Plasse *et al.* (1970), have reported important seasonal influences on length of estrus cycles. These Florida researchers reported that Brahman heifers averaged 29 days, with the longest cycles occurring during the winter season. The conflict among the reports may arise from differences in the frequency of observation of estrus or from the indirect effects of climate—e.g., changes in nutrition—rather than from the direct effects of a hot or cool season.

Postpartum Estrus

The average interval from parturition to first observed estrus is 35–45 days during first lactation and 50–75 days during later lactations in U.S. dairy herds. This is not the usual case for warm climates due to some of the factors already enumerated, such as underfeeding, but other factors may be involved. In a Holstein herd in the lowland tropics of Venezuela, 69% of the cows had at least one estrus by 65 days postpartum but only 12% of the cows showed evidence of estrus between 70 and 120 days. This pattern of behavior was attributed to level of feeding since the cows did not begin to gain in body weight until 100 days or more in lactation. After the problems of poor feeding had been rectified, the incidence of estrus and the intensity of expression of estrus were still much less than desired. The causes were unidentified; but delayed involution of the reproductive tract as a direct effect of environmental stresses and abnormal levels of progesterone were suspected.

According to the findings of Trimberger and Fincher (1956), the variability in length of time until first postpartum estrus may be more a matter of expression than actual delay. Their examinations revealed that 82% of 200 Holstein cows were in estrus by the sixteenth day postpartum but only 71% showed signs of estrus. This may be the case in the tropics. The studies of buffaloes in India lend support to the hypothesis of quiescence. However, much more research is needed on this point.

For Zebu type cattle the interval from parturition to first estrus is longer—up to 100 days—than that reported for Criollo cattle in Latin America and some breeds of Africa (40–80 days), even when all were milked without the calf present. Since Zebu cattle ordinarily do not show strong expression of estrus, as judged by mounts, etc., estrus is

difficult to detect in these cattle. Plasse *et al.* (1970) reported that the incidence of quiet ovulation in Brahman heifers was 26% of all ovulations and the incidence was higher in summer than in winter for herds in Florida.

Conception rates are especially low for breedings at less than 30 days postpartum (<5%). The rate of conception from 21 to 40 days is around 50%, 41–60 days, 54% and over 61 days, 75%. Thus at least a 50-day postpartum interval is recommended before first breeding. There is evidence from Britain that very early mating may actually delay ultimate conception (Dawson, 1967). So unless estrus is delayed more than 60 days postpartum, breeding efficiency may not be seriously impaired. Still, it is desirable to have evidence of normal cycling, as expressed by estrus, one or more times before the expected time of breeding. Early cycling indicates normal involution of the reproductive tract and little problem of infection or disease.

Long periods of anestrus occur in some herds due to several causes, such as dystocia resulting in uterine damage, followed by metritis. Anestrus is more frequent after first than subsequent calvings. Suckling also seems to delay onset of estrus. The work of Wiltbank and Cook (1958) showed that Milking Shorthorn cows suckling calves averaged 152 days from calving to conception, versus 94 days for milked cows. Many other reports associate lower conception rates and long calving intervals with the stress of lactation and calf weaning practices.

Researchers in Rhodesia and Zambia have attempted to stimulate sexual activity in Africander and indigenous cattle, either through early weaning of the calf or by use of a vasectomised bull with the cow herd before weaning (Symington and Hale, 1967). Both methods increased conception rate slightly. The presence of the vasectomised bull apparently stimulated ovulation in some cows and ovulation plus estrus in others.

The duration of estrus in cattle is often shorter in warm climates than in temperate climates. In Florida the average duration for Brahman females was 6.7 hours, with about 66% between 2 and 8 hours duration. The majority of the estrous periods commenced during daylight hours but the number of ovulations was greatest during the hours of darkness. The average time of ovulation was 26 hours after the beginning and 19 hours after the end of estrus (Plasse *et al.*, 1970). Dairy cows and heifers in Louisiana averaged 11.9 hours, with heifers having longer periods than cows; ovulation occurred 12.4 hours after the end of estrus. Under these conditions, it was found that optimum

time for insemination was 7–12 hours after the onset of estrus. In the same study anestrus occurred one or more times in 33.4% of the females, representing about 11% of the expected estrous periods. It was estimated that anestrus would have increased 20% with only 6:00 A.M. and 6:00 P.M. observations (Hall *et al.*, 1959). In a tropical area of Mexico estrus duration averaged 13.2 hours (range 4–30) in dairy cows that subsequently conceived and 10.3 hours (4–36) in cows that did not conceive. Insemination 22 hours after estrus resulted in 33% conception (Cuevas and Hagen, 1966). In some East African cattle herds estrus lasted only 2.5 hours, even though the females were attractive to bulls for 26 hours (Rollinson, 1963).

In temperate areas, the average duration of standing estrus of cows is 16–20 hours (range 2–28 hours) but somewhat less in heifers, 12–18 hours. Best conception rates have been obtained from breeding not less than 6 and not more than 24 hours before ovulation. Although opinions differ on the duration of estrus and the best time for breeding in warm climates, as contrasted to temperate areas, it is relatively clear that conception rates could be improved by inseminating at an earlier stage following the observation of estrus than is the practice in temperate areas.

Disease

Almost any infectious agent that has a detectable effect on the animal may interfere to some degree with the reproductive cycle. In cattle, this varies from infections of the reproductive tract to nutritional disorders, such as diarrhea, or direct effects of pathogenic conditions, such as foot rot. Heavy infestations of internal parasites may delay or prevent onset of estrus, as may aftosa, anaplasmosis, and other diseases.

Diseases of the reproductive tract frequently reduce fertility or create temporary and even permanent sterility. The most common are brucellosis, vibrosis, trichomoniasis, and leptospirosis. Of these, brucellosis is most prevalent and damaging, inasmuch as abortion rates may be high in an infected herd. The other diseases can also cause abortion or reduce fertility. Strict control and testing programs are the only means of decreasing reproductive diseases. Some, such as brucellosis, can be controlled by vaccinations. There are also vaccines against leptospirosis, but their effectiveness remains subject to conjecture. Trichomoniasis and vibrosis usually respond to antibiotics, but seriously affected animals should be removed.

Other Factors

Cystic follicles—commonly referred to as cystic ovaries—are rarely encountered in sheep, but are fairly common in cattle and swine. A cystic condition may be caused by a failure of the adrenal glands to produce enough luteinizing hormone to bring about ovulation. Cystic follicles cause (1) continuous estrous behavior (nymphomania), (2) anestrus, or (3) cyclic estrous cycles approaching a normal condition. The nymphomaniac condition is most dramatic: the female continues in estrus for prolonged periods but does not conceive. There is some evidence that this condition is more prevalent in warm climates. It is suspected that the condition arises when a small corpus luteum develops, enough to produce estrus, but not ovulation; the corpus luteum remains on the ovary, causing repetition of estrus. Some animals recover spontaneously, and others can be restored to normalcy by hormone therapy with gonadotrophins. But if male characteristics have developed, the animal will not respond to treatment.

The two other cystic conditions—anestrus and cyclic estrous cycles—seem to occur fairly frequently. How best to arrest them is another unsolved problem of reproductive performance in the warm climates. Some recommended the use of gonadotrophins to stop anestrus, but this remains somewhat controversial. The cyclic estrous cycle is associated with lack of strong expression of estrus. Preliminary tests conducted in Louisiana (Roussel *et al.*, 1970) indicate some supplementary progesterone, such as MGA, may be helpful in getting a stronger expression of estrus and perhaps assure ovulation but more research is required before recommendations can be made. As pointed out above, the use of a vasectomised male or nymphomaniac cow running with a herd may aid in obtaining a stronger expression of estrus.

Sometimes there is a problem of persistent corpus luteum which has almost the opposite effect of cystic follicles in that the female fails to show estrus or if she does, she fails to ovulate. A persistent corpus luteum may also denote some infection in the uterus. The condition may alleviate itself in time or respond to treatment by expressing the corpus luteum manually from the ovary. The use of gonadotrophic hormone treatment, such as pregnant mare serum, is recommended.

Frequently, delayed conception is caused by an infection in the uterus, commonly referred to as metritis. This condition often follows dystocia or incomplete expelling of the placenta. The level of infection may be low or high, but in either case it will interfere with implantation. If the condition is observed before it causes large accumulations of pus in the uterus, antibiotics, either by injection or by

implanted capsule, are effective in treatment. Some recommended drugs and hormones for treatment of metritis and other reproductive problems in cattle are listed in Table 12.6.

TABLE 12 6
Some recommended hormones and drugs for treatment of reproductive problems in cattle.

Reproductive problem	*Hormone or drug*	*Dosage*
Metritis		
Mild cases	*Lugol's* solution (stock solution)	40–125 cc intrauterine infusion of 2% of stock solution in physiological saline.
Severe cases	*Lugol's* solution (stock solution)	40–125 cc intrauterine infusion of 4 5% of stock solution in physiological saline. Repeat treatment at 3–5 day intervals until infection clears up
Postpartum uterine involution	*Furacin*	40–125 cc intrauterine infusion of furacin solution
Ovarian cysts	*Chorionic gonadotrophin* (anterior pituitary-like hormone)—HCG produces primarily luteinizing effects Some of its effects are, however, similar to those produced by FSH of the anterior pituitary gland	2500–5000 I U slow intravenous or 10,000 I.U intramuscular injection Repeat at weekly intervals, if indicated
Disturbances of an early pregnancy (threatened and habitual abortion) and sterility due to defective luteal function	*Pregnyl* (chorionic gonadotrophin)	5,000–10,000 I.U intramuscularly daily
Anestrus (functional)	*Estrovarian, aqueous* (Contains estrone with acadia, procaine hydrochloride, thimerosal, and solium chloride)	1 0–2 0 cc intramuscularly.
Nonfunctional ovaries, anestrus, or hypofunction of the ovaries	*Vetrophin* Contains follicle-stimulating and luteinizing hormones essential to normal estrus	5–10 rat units intravenously. If normal estrus does not occur in 10–14 days, give second treatment
Retained corpus luteum, retained placenta, mummified fetus, etc	*Stilbestrol—long acting* Diethylstilbestrol in a special base, which gives prolonged estrogenic activity	2 0–4 0 cc per 500 kg body weight intramuscularly
Intrauterine infections following calving	*Uterine boluses* Contain urea, sulfathiazole, sulfanilamide, and acriflavine	Insert 1 or 2 boluses deep into uterine cavity Repeat in 3 days if necessary

Source Courtesy of C Branton, Louisiana State University

Occasionally the uterus will be expelled with the fetus The prolapsed uterus can be replaced successfully provided it is discovered very early and stitches are taken in the vulva to prevent re-expelling However, the repeatability of the condition is high, so when it happens, it is wise to remove the female from the herd as soon as convenient

Breeding efficiency in dairy herds may decrease slightly with increasing herd size, either on natural service or artificial insemination, due to a decline in individual cow attention, but this is usually not serious In beef herds conception rates tend to be lower in multi-sire herds than in single sire herds even though the number of cows per bull is less It has been shown, for example, that the average calving percentage for single sire herds with 28 cows per bull was 87%, compared to 81% for multi-sire herds with 18–19 cows per bull This was probably related to bull behavior, some bulls in multi-sire herds monopolize a larger number of cows There is evidence that higher conception rates can be obtained in herds of fewer than 75 cows than those with more than 75, nevertheless, good levels of conception can be obtained with 50–75 cows and 2 bulls

Breeding efficiency tends to be lower in high producing herds than medium producing herds In Poland, for example, cows with an average yield of 5500 kg per lactation had an average calving interval of 16 3 months, as compared to 15 months for cows producing 3500 kg In Louisiana, there was a significant positive correlation between total milk yield in the first 120 days of lactation and calving interval Although the evidence cited stems from European breeds, it is very likely that the same will hold true for tropical breeds In fact, the calving interval in the Sahiwal herd at New Delhi, India, has lengthened with increased yields These observations indicate that careful husbandry is needed to prevent lowering of breeding efficiency with rising milk production, otherwise, the benefits of higher yields will be lost through longer calving intervals

Reproductive efficiency declines with increasing age, especially after 10 years, in European breeds of cattle The length of breeding life appears somewhat longer in breeds indigenous to the tropics, but as pointed out in Chapter 10, this may be a misnomer when breeding life is judged on the total number of calvings instead of age

There is a negative correlation between age of first calving and breeding efficiency during first lactation in both European and Zebu dairy herds Thus the calving interval between first and second lactations is usually longer than in subsequent lactations This is probably because the younger animal has a higher demand on energy intake for growth and development than older cows

Early calving (<2 5 years) is attractive in beef herds but often-

times those calving first at around 2 years of age will fail to breed back during the subsequent breeding period, resulting in no more calves by 5 years of age than females which calved the first time at 3 years of age. To have beef heifers calve at 2 years of age and maintain good performance later requires well developed animals, which in turn requires good feed resources.

There is evidence that age of calf at weaning has a significant effect on subsequent calving rate in Angus, Hereford, Brahman, Brangus, and Santa Gertrudis cattle. Also, cows calving early in the spring months seem to have the greatest chance of repeat conception because they have more opportunity to breed in a controlled breeding period (Warnick *et al.*, 1967).

In herds where artificial insemination is practiced, the efficiency of the inseminator and heat detection are critical to the success. In studies made in New Zealand, 11.3% of the total variance in conception rate among dairy herds was due to variation between technicians.

The distance animals must walk to graze or watering points can have a bearing on conception rate. Movement of cattle from one group to another may also be a factor. Each time a cow is introduced into a new group she will be challenged to establish her position in the peck order. This detracts interest from mounting or identifying those in heat. Likewise, moving cattle from one location to another or from the temperate zone to the tropics usually disrupts breeding efficiency.

Delay in shedding of hair coat often accompanies retardation in the onset of estrus, particularly among European breeds imported to the tropics or subtropics. Whether retention of the long hair coat is a direct cause of lack of estrus or a visible expression of some internal imbalance that is the inhibitor is yet unknown.

In some species, certain anatomical features may cause reduced fertility, such as the heavy fat-tail characteristic of some indigenous sheep. Rams of the same breed seem aware of the need to push the tail of the ewe aside with head or foreleg as they mount for service, but mating of fat-tailed ewes with imported breeds may cause problems unless man assists by holding the tail of the ewe aside.

WAYS OF IMPROVING BREEDING EFFICIENCY

Role of Manager

Get a good manager. He determines the success of the operation in reproductive efficiency. His importance can be seen from Table 12.7, which shows the changes in the breeding efficiency of a herd under three different managers.

TABLE 12.7
Influence of herd manager on breeding efficiency in a dairy herd

Measure	*Manager* A	B	C
Days from calving to first estrus	50	84	40
Services per conception	1.7	2.5	1.3
Days from first service to conception	34	76	26

Continuous surveillance and record keeping enhance breeding efficiency in numerous ways. A good manager knows that irregular estrous cycles or vaginal discharge at any time are signs of possible infection somewhere in the reproductive tract. He is also aware that cows with retained placenta should be examined and treated 24 to 72 hours postpartum and these should be re-examined one or twice prior to breeding to ensure that the uterus is free of apparent infection and has returned to normal size. Cows without retained placenta (but who show a purulent or fetid discharge) should be examined and treated. He knows that examinations are desirable (1) when he observes an abnormal or cloudy mucous during estrus, (2) 30 to 50 days postpartum to make sure the reproductive tract is undergoing involution at a normal rate, (3) 24 to 36 hours after service for cows bred 3 or more times to determine the cause of breeding difficulty, and (4) 45 to 60 days post breeding to detect pregnancy.

With proper records the manager can determine if the number of repeat breeders—those bred more than three times—exceeds 10% of the herd. If so, he looks for the cause, such as time of breeding. If the conception rate is higher from natural service than from frozen semen, time of breeding, quality of semen, and insemination techniques should be checked. If metestrus bleeding occurs under 24 hours after service, the cows were bred too late. If it occurs over 36 hours after service, they were bred too early during estrus.

Short irregular intervals for estrus frequently indicate cystic follicles, whereas, both short and long irregular intervals indicates to the manager that heats are being missed, there may be an infection influencing the cycles or undernutrition, as well as some other stress.

The manager makes the difference between profit and loss at time of parturition. A good manager literally lives with the flock or herd at time of parturition. He gives assistance during parturition if needed, coaxes mothers to accept unwanted offspring, teaches the young to suckle, dries off the newborn to prevent chilling, prevents young from

drowning during the rainy season; records birth along with condition of offspring and dam; observes for abortions; estimates, by close observation of development of young, the "best milkers" in the herd or flock; treats the animals to prevent disease or parasites, such as dipping the naval in iodine to prevent screwworm infestation; and performs castrations.

Detecting Estrus

The use of artificial insemination (AI) in tropical areas has been disappointing largely because of unsatisfactory detection of estrus. Estrus detection has always been a difficult problem. The standing mount will identify 50% or so of the cattle in heat in the tropics but it is of little or no value for sheep or swine. Therefore, it is obvious that more than the standing to mount of females is needed for good reproductive efficiency.

Herd management practices, especially in dairy operations, account for some of the difficulty. Where herds are crowded into small lots, there may be little opportunity for heat detection. When lots have a concrete surface that is continuously wet the females may be reluctant to mount others for fear of injury. Furthermore, observations for estrus are often relegated to time of feeding. This approach is inefficient as the attention of the animal is directed toward eating and not mounting. Such management factors contribute to failure to diagnose estrus in cows having essentially normal cycles.

In Louisiana, it was found that increasing the frequency of observation of cattle from once or twice to 3 and 4 times per day increased significantly the number of cattle observed in estrus, particularly heifers of breeding age. Driving a truck, riding a horse, or walking among the animals helps in estrus detection as these actions stimulate movement. In Argentina and elsewhere it is common practice to observe cattle just at dawn as they rise from resting.

Another problem is that when AI is the method of breeding, this imposes additional disciplines on the animal caretaker's daily routine. Unless his understanding of the principles underlying the purpose is clear and he is fully in sympathy with his responsibilities, it is only human for him to devote less than full attention to heat detection. Thus training of workers is an important aspect of management. Included in the workers' training should be the recognition of all symptoms of estrus. Standing when mounted by another animal represents the final criterion of estrus, but many behavioral changes indicate approaching estrus. In cattle, these include restlessness, bawling, butt-

ing, redness of the vulva, and a clear vaginal mucous discharge Cows may mount each other at almost any stage of the cycle, so mounting behavior is not necessarily an indication that estrus is impending

Metestrus bleeding usually occurs on the second or third day of the cycle If the dried blood is observed on the tail and the date recorded, this can be used to predict the next estrus Maintenance of heat expectancy charts is well worth the effort

For dairy herds, it is recommended that all cows that fail to show estrus within 50 days after parturition be examined by a veterinarian If the animal has pyometria, or some similar condition that may interfere with normal ovarian function, she should be treated If a corpus luteum is found, indicating that the ovary is functioning, the stage of the cycle should be estimated from the size and consistency of follicles and corpora lutea and consistency of the uterus noted in order that the animal may be checked more carefully at the next expected estrus

Estrus can also be detected in cattle by means of teasers—vasectomised bulls or bulls in which the penis has been amputated and the urethra exteriorized, or hormone treated cows or steers—and heat checking devices If a teaser bull is used, precaution should be taken against the spread of disease, a vasectomised bull is less preferred for this reason Hormone treated cows or steers reduce the risks of spreading disease, but it is difficult to treat them in such a way that they are willing to mount This is an even greater problem in hot climates

The heat checking devices available are usually attached to the tail or rump of the female Mounting causes these devices to discharge a marking fluid, which can afterward be observed Another device gaining acceptance, which may be used for all species, is the "Chin-Ball Mating Device" made by Frank Pavouir Ltd , Mahana Road, Hamilton, New Zealand It consists of a small stainless steel box mounted on a special halter beneath the chin of the animal being used as a checker The box is filled with a special dye, which is exuded around a spring-loaded ball and marks the back of the animal in heat when mounted The principle of the device is similar to that of a ball point pen

In the Soviet Union an apparatus has been employed that consists of a pocket ohmmeter with electrodes, which are applied to the mucous membrane of the vagina The resistance indicated on the ohmmeter shows whether the female is ready for service Although it has been found most useful for cattle, it has also worked with swine and sheep

An additional reason for paying close attention to estrus detection is to identify aborting females as early as possible for removal from

the herd or rebreeding. Females aborting in less than 150 days after service may go unnoticed unless it is the practice to observe females closely for discharge. Abortions beyond 150 days will leave an evident residual placenta for a few days if a fetus is not found.

The signs of estrus are not very apparent in the ewe, but this is unimportant if the ram is with the flock at breeding time. Where hand coupling is practiced, it is advisable to run a teaser ram with the flock. He may be a vasectomised ram or an intact male with an apron hung in front of the penis to prevent service.

It is common practice in some areas for livestockmen to smear the brisket of a ram or bull with paint or a paste made from grease and coloring material at about 2-day intervals to denote when each female has been served. The color of the paste may be changed every 16 to 18 days in sheep and 18 to 21 days in cattle so that females that again come into heat may be discovered. This practice serves additionally to detect sterile or poor libido males.

Estrus in sows is preceded by a swelling of the vulva and a slight discharge. In addition to the swelling, which continues during estrus, the sow shows general excitement and often follows other sows, sniffing at their genital organs and mounting them, while grunting in a peculiar fashion. If the sow stands to be mounted or stands when a hand is placed firmly on her back, she probably is in or near to estrus. Ovulation occurs about 35 hours after the onset of estrus; but since the vitality of the eggs is low after a few hours, the second day of estrus is the most favorable for service. In gilts, the eggs appear to be shed slightly earlier than in sows. Sows often show signs of estrus 3 to 5 days after farrowing, and a second estrus usually occurs 3 to 5 days after weaning. The general recommendation is not to breed during the first estrus, due to heavy lactation, but to breed on the second.

Synchronization of Estrus

There are numerous advantages in being able to regulate estrus cycles in domestic animals, chief among them being increased potential for expansion of artificial insemination in swine, sheep, and beef cattle. Over the past decade a great deal of research has been directed toward practical methods of cycle regulation in sheep, cattle, and swine. Considerable progress has been made, but no entirely practical and generally accepted method for any of these species has yet been developed (Hansel, 1970).

MAP and similar progestins have proven useful in controlling the

estrous cycles of cattle and sheep Conception rates of 50–60% can be obtained in cattle bred at the first estrus after feeding 180–200 mg per day for 18 days A higher percentage of the treated animals come into estrus 2–5 days after withdrawal of the compound from the feed (Hansel, 1970) However, the quantity of MAP needed to effectively suppress estrus makes it rather expensive for wide use Consequently, a number of other orally active progestational compounds have been tested, with some effective at very low levels For example, a compound identified as CAP will inhibit estrus when fed at the rate of 10 mg per day, and melengestrol acetate (MGA) is effective at 0 4 mg per day Rather low fertility of females bred at the synchronized estrus remains a problem To reduce the necessity of feeding and to overcome the problems of each animal obtaining its required daily intake, efforts have been directed toward suitable hormone implants, the removal of which will induce estrus Most methods have given reasonably good synchronization but the fertility remains lower than for untreated animals

A technique of administering progestins for estrus cycle synchronization of ewes by way of impregnated polyurethane sponges inserted into the vagina has given good results following removal of the sponges after 16 days (Robinson *et al* , 1967) But the technique has not been successful in cattle because many of the cattle fail to retain the vaginal pessary the required length of time

At this stage of technology, estrus and ovulation can be regulated in cattle and sheep by administering a number of different progestins either orally, subcutaneously as removable implants, or intravaginally by way of impregnated sponges A major difficulty is that the fertility of females synchronized with the compounds have lower fertility than non treated animals Most of the methods still require checking for estrus after withdrawal, however, reasonably good conception rates have been obtained by inseminating synchronized cattle fed MAP on two successive days—the third and fourth following withdrawal Estrus synchronization in cattle and ewes is most useful for timing of breeding, concentration of labor etc , but does not enhance fertility And to be used effectively it requires skill on the part of the operator

A significant proportion of gilts fed progestins in sufficient amounts to inhibit estrus develop cystic follicles in their ovaries after withdrawal There is some evidence that this problem can be overcome by feeding an orally active estrogen for 9 days followed by 9 days of MAP feeding In other tests the proportion of heats synchronized within a period of two days has been increased by administering 1000 I U of pregnant mare serum after withdrawal of the progestin

compound Metallibure. In spite of less than completely satisfactory results on synchronization of estrus in swine, it has been the means of commercial use of AI.

Ultimately, it should be possible to control the time of ovulation to the point that it will be unnecessary to check animals for estrus before insemination. When this day arrives the procedure should prove a boon to livestock improvement, particularly in beef and sheep production.

As indicated by the Louisiana experiences cited above, the compounds used in estrus synchronization may also prove useful at a low level for increasing the intensity of estrus and as an aid in stimulating ovulation when the corpus luteum does not develop to the point that ovulation occurs.

Determination of Pregnancy

The most common method for determination of pregnancy in dairy cattle is keeping track of 60–90 days non-returns. Other standard procedures include palpation of the uterus 35–45 days post breeding. However, recent evidence indicates that palpation should be practiced only after 50 days. (This is more desirable than 30–45 days as it seems this period is very critical to the new embryo and pregnancy may be easily voided). Under intensive or semi-intensive management, palpation is often a profitable practice for cattle operators. For extensive livestock operations, recording of the number of young is about all that is warranted. Ultrasonic devices have proven successful for detecting both pregnancy and number of fetuses being carried in ewes on an experimental basis.

Culling for Sterility

The farmer is consistently confronted with decisions as to when to remove females from the herd or flock for poor breeding efficiency. Frequently, farmers are not as cost conscious about culling as they ought to be. Recommendations on culling for sterility causes other than disease or obvious serious infections of the reproductive tract are difficult. The rules must be flexible for numerous reasons. The farmer will tolerate poorer breeding efficiency from good performers than from poor performers. If he is selling breeding stock for attractive prices he may tolerate one offspring in two years or more. When herd numbers are stabilized, tolerance to long dry periods will be less than

not hasten to make blanket recommendations, for it is obvious that we are far from having the answers on the most suitable technological procedures for warm climates

THE MALE IN REPRODUCTIVE EFFICIENCY

Bonsma, (1968) strongly recommends that serious consideration be given to the "masculinity" of the herd sire He contends that no male should be used with abnormalities of the sex organs, such as hypoplasia of one or both testicles The bull should have masculine appearance, have clearly defined secondary sexual characteristics and not be too compact in body Although there is little scientific evidence that points of apparent masculinity are directly related to breeding efficiency, from the practical standpoint these points may warrant consideration, especially if the bull is to live and work under range conditions

Sexual behavior of males is a problem in certain countries and may be associated with particular breeds It is also a problem in artificial breeding units, where low sex drive and inability to ejaculate limit the usefulness of sires In the U S , about 61% of AI bulls are culled for low fertility, poor semen, and refusal to serve (Salisbury and VanDemark, 1961) Certain breeds, such as Brahman, Sahiwal, and Red Sindhi are "shy breeders," which means they do not lend themselves to very satisfactory AI service

In many Zebu breeds there is a high frequency of bulls without good sex drive, as indicated by the proportion in Table 12 8 that were slow or unwilling to serve The poor drive on the part of the Sahiwal is a serious handicap to its use in AI Reports form Kenya, where Sahiwals have been used for grading up, confirm that these bulls are very slow to respond to collecting for AI

TABLE 12 8
The mating performance of various Indian breeds of cattle by percent of total in each category

Breed	No	*Quick*	*Slow*	*Very slow*	*No sex drive*	*Unwilling to serve*
Sahiwal	22	13 7	27 3	50 0	4 5	4 5
Red Sindhi	115	32 2	27 8	21 8	9 5	8 7
Tharparkar	28	28 6	32 1	25 5	10 7	3 6
Hariana	230	45 5	25 2	23 5	5 7	0 4

Source Adapted from Lagerlof, 1962

Brahman bulls which have an opportunity to mate with cattle of their breed or other breeds, choose Brahman females in preference to European breeds (Hale, 1966). Zebu type bulls appear more active as breeders at night. If a man walks near a Zebu bull at night, the bull will likely break his mount and go away even though the cow may show distinct signs of estrus.

Bulls of Zebu breeds also reach sexual maturity late, as compared to European breeds. Seldom are bulls of any breed from the tropics put in service before 2½ to 3 years, and sometimes later. Although the late maturity is influenced by level of feeding, there is also evidence of genetic influences. In the U.S. it was found that each 25% Red Sindhi breeding in Red Sindhi-Jersey crosses delayed sexual maturity by about 2 months in the crossbred males.

Some observers in Africa and Latin America contend one cause of low breeding efficiency in the herds is because far too many immature bulls are used. This is probably because young males are not separated during prepuberty. Also, herd owners tend to depend on younger bulls for breeding since they are smaller in size than desired for the best market price.

Frequency of collection, pre-collection stimulation, nutrition, and age and size of the bull all influence the production of good quality semen. Though semen volume and sperm concentration are reduced by frequent ejaculation, collection up to 14 times per month does not seem to affect fertility in most cases. Salisbury and VanDemark (1961) describe an experiment in which semen was collected from 2 groups of 10 bulls, either once per week or daily. Although the non-return rates of the two groups were similar, the group used daily produced nearly twice as much spermatozoa per week. In some Indian breeds, semen collection twice per week had an adverse effect on semen volume and concentration and 4 collections per week adversely affected reaction time.

If grazing is poor the libido of bulls and rams will decline and may even reach a point where they leave the herd or flock. Rotating males in and out of the herd periodically—every 2 to 4 weeks—has proven very effective in overall breeding efficiency. Such a practice will require more males and labor but the increase in number of offspring should make it worthwhile.

Inbred boars often lack libido (Hauser *et al.*, 1952). The cause is unknown but it is believed that an imbalance or deficiency of testosterone production is the main factor. It is not considered advisable to treat for the condition because treatment has met with limited success and also because continued use of such boars may increase the condition in the population. Treatment of boars with gonadotrophic hor-

mones for the correction of defective spermatogenesis is likewise considered inadvisable

Reports of experiments from the Soviet Union indicate conception rates in cows of 86% with mixed semen of two or more bulls, versus 67% for unmixed semen, with a resulting improvement in embryonic vitality and more vigorous progeny Sows were also reported to have larger litters from mixed semen matings Experiments along these lines in Britain and the U S have not been this conclusive, some have indicated a slight improvement with mixed semen and others have shown no advantages Russian experiments also indicate 10% higher conception rates when 10% ram semen is mixed with bull semen, but this has not been confirmed elsewhere

The practice of double mating during estrus will increase con ception rate but it is usually not economically feasible for commercial production Nevertheless, it may be useful where hand mating is practiced or where the manager has access to semen stored on the farm

Adjustments that can be recommended for the male side of livestock reproduction include (1) selection of males that are well grown and show good libido, (2) checking for fertility prior to placement in service, (3) adequate feeding prior to and during the service period, (4) flushing of males prior to the breeding season, (5) rotating males in and out of the female herd if the feeding is poor or the service period is long, (6) elimination of males that indicate any signs of hypoplasia, and (7) hand mating to extend the use of the best sires

If service is by AI, breeding ought to take place twice per day in warm climates It is generally recommended that cows in estrus in the morning be bred late in the P M and those observed in estrus during the P M bred the following A M Some breeders are following this practice, adding a second breeding for cows that will still stand to mount in the next service time

Again, as with the recommendations for improvement of re productive efficiency in the female herd, adjustments on the male or insemination side depend on the economic feasibility and skills of personnel

USE OF ARTIFICIAL INSEMINATION

The physical process of artificial insemination is feasible for all classes of livestock and poultry with reasonably satisfactory conception rates Frozen semen may be used with cattle, but with other animals fresh

semen must be used, and thus the conditions required for satisfactory service are not often economically practical. Nonetheless, it is undisputed that the proper employment of AI provides a universal means for limiting the spread of venereal diseases and making possible certain naturally incompatible matings. Like other phases of technology, it affords advantages but under other circumstances it is unwarranted at present.

The principle advantages of AI are: (1) AI enables an individual male to sire a large number of progeny, thereby requiring fewer males, which gives an opportunity to increase the superiority of the males saved. (2) An AI progeny test is the most accurate means of evaluating males for use in a variety of environments. (3) Crossbreeding plans can be carried on more effectively when sires are available through AI; it eliminates the need for each herd to maintain males of two or more breeds. (4) Males that carry undesirable recessive genes are more likely to be detected because of the greater number of offspring in AI than in natural service. (5) Germ plasm is available to herd owners who would not otherwise have access to it. (6) AI permits selected matings of outstanding individuals and provides a means of mass breeding if used in conjunction with feeding for synchronized estrus. (7) AI is the most economical means of upgrading indigenous stock with improved breeds and moving animal germ plasm about the world. (8) One other advantage frequently overlooked is that AI may serve as a means of bringing farmers—particularly, small farm operators—and trained personnel into closer contact. This could serve as the best approach to initiation of improved management practices.

Although AI affords advantages, it has limitations. From the standpoint of genetics, inbreeding effects may accrue more rapidly than desired if too few sires are used; it is contended that the frequency of deleterious recessives may increase. The latter is a somewhat untenable argument, as only genes already in the population can be spread.

Some nongenetic disadvantages of AI are that conception rates may be less than for natural service due to many causes, among which are handling procedures, improper storage, improper time of breeding in the estrus cycle, and ineptness in heat detection. Costs per pregnancy may be higher due to added expenses.

Frozen semen is, of course, becoming widely used in several countries in the N-S 30° latitudes, but to date the conception rates have not been as good as expected, especially for bovine semen imported from the north latitudes. In Venezuela and India the conception rate for imported semen has been running 20 to 37% for first service. There could be many causes but even where the storage and

handling have been well checked and the inseminators adequately trained, the conception rates for imported bovine semen appear to be at least 10% less than in the U S This indicates a need for further examination of the suitability of freezing and handling procedures for semen used in tropical areas Semen storage techniques may be one factor

The Japanese pill technique and the French paillet (straw) method may overcome some of the problems encountered with use of glass ampules or pipettes in handling frozen semen A field trial in Cuba showed that for 989 inseminations with semen stored in "straws," the conception rate was 64%, and with 892 inseminations the pill gave a conception rate of 70% These rates were considerably better than the 58% conception rate obtained with the ampule The Cuban group concluded that the Japanese pill technique is the simplest and most economical for tropical conditions Experimental trials in Brazil, Taiwan, and Argentina have also shown improved conception rates with the pill insemination It has been suggested that the use of either the pill or straw, which reduces the fluid volume used in insemination without reducing concentration of sperm, affords advantages in hot climates It is conceivable that the liquid nitrogen storage process currently in use, especially in the field, may permit storage of semen as pills or straws at a more constant temperature than is possible for 1 cc ampules mounted on canes When the tanks are maintained under rather high external environmental temperatures, the ampules on the upper portions of the canes may be affected, particularly when the nitrogen level in the tank is rather low Probably when a canister in the storage tank is lifted up for the removal of an ampule, other ampules near the top of the canister receive more of a temperature shock than they would in cooler climates These are problems that must be investigated if AI is to be used effectively in the tropics

Problems in Making AI Effective

AI could be a very useful part of any of the breeding programs outlined in Chapter 10 (Figures 10 13, 10 14, 10 16, and 10 17), particularly for cattle It is likely, however, that insufficiently trained personnel, geographical hazards, and lack of means for development of sires of superior merit through progeny test will restrict practical justification to use AI for grading up local types with imported stock (Figure 10 16) and the production of crossbred sires with semen from imported stock for use on the general population (Figure 10 17)

The success of AI programs is limited not only by physical and economic factors, but also by the distrust of the local farmers. They must be convinced that animals of improved quality will bring them higher returns. Where there is insufficient purchasing power in the market to pay premiums for quality products or inability of the farmer to provide the improved level of nutrition needed, the distrust may be well justified.

The acceptance of the use of AI by a large segment of the dairy industry in the temperate zones has been attributed to a number of factors. (1) Conception rates, even with frozen semen, have been as satisfactory as with natural service. (2) No appreciable changes in labor and facilities have been required. (3) AI has been looked upon favorably by breed organizations. (4) Its development has been sponsored largely through farmer cooperatives. (5) Farmers have participated in the selection of sires (sire committees). (6) There was an awareness among farmers of the need for performance testing and that family selection is required in the selection of bulls since there is no direct measure of milk production. (7) It was recognized that AI would be valuable in the expediency of genetic progress. (8) And there has been cooperation among AI organizations in the distribution of semen (Miller, 1968).

Obviously these developments took time. An effective extension program was operating and the managerial skills of the farmers were good to excellent. In short, they knew their stock; hence they could appreciate the potential both for savings on cost of sires and for genetic improvement. Possibly even more significant than the opportunity offered for genetic improvement were the facts that conception rates were acceptable and that no appreciable changes were required in the farm operations. The importance of the latter is evident by the fact that more than two-thirds of the dairy heifers in the U.S. are still bred for the first pregnancy by natural service. Breeding by AI would require significant modification in the customary way of handling heifers on the farms.

Currently, in the U.S. less than 3% of the beef cattle population are bred artificially, as compared to about 50% of the dairy cattle. The slow acceptance of AI in the beef industry has been primarily due to economics since major changes in husbandry practices would be required. Most commercial breeding herds, whether in the U.S. or some other country, are characterized by large holdings and large ratios of cattle per worker. The cattle are so widely dispersed that they may not be checked for days at a time, thus prohibiting proper observation for heat. The increase in labor and facilities needed for AI would make it a poor investment.

Another inhibitor to acceptance is that progeny testing is somewhat less critical in beef production since some of the more important traits—e g , rate of gain—can be measured on the males directly Even so, the selection differential that could be achieved with AI has advantages over any system involving herd sires It has been estimated that the optimum use of AI could speed improvement in weaning weight, rate of gain, and carcass traits by 200, 50, and 300%, respectively

Lack of satisfactory means of deep freezing of boar and ram semen, coupled with the low monetary value of the sow or ewe compared with that of the dairy cow, makes AI in these species costly Where AI service is available on a routine basis, the annual cost of service for a cow is about 2–4% of her value For a sow or ewe, this would be only $0 50 to $1 50 It is questionable whether semen alone could be furnished within this price range For this reason many feel that AI will not be pushed in swine or sheep The fixed costs associated with a ram or boar stud may not be greatly different from those for a dairy stud except for the initial cost of the animals An added problem with these species from the standpoint of stud operations and the use of professional inseminators is the seasonality of breeding in these species This will be a serious drawback unless dairy operations can be serviced by the same inseminators Such arrangements are uncommon for sheep but may prove workable for swine

Methods for the control of the estrous cycle, the reduction in the risks of spreading disease from farm to farm by transporting boars, and the wider use of superior boars will no doubt be conducive to AI for swine in certain areas Currently in the U S several AI establishments have expanded their operations to include boars In these areas, herd density is high and swine are being serviced by inseminators working dairy herds Under these conditions, AI in swine appears economically feasible

Only the Soviet Union has embarked on a national program for AI for sheep In other areas, such as Europe and the U S , AI has been used principally for planned matings in breeding flocks and to a small degree for extending the use of valuable sires in commercial flocks In Australia, AI has been used to introduce the polled gene and, by selected matings, to improve wool production Dunlop and Young (1961) concluded from a theoretical comparison of the merits of natural and AI service for wool production in Australia that AI would be superior by a margin of 18–26%, but natural service would yield more rapid progress for a flock of 1,000 ewes or less This was mainly because of the depressing effects of inbreeding that would result from the use of a small number of rams They concluded that genetic prog

ress would be slowed through the use of AI on an intraflock basis even if the flock were sizable. In brief, it seems that in countries where sheep have developed fully along traditional lines, such as in Britain, Australia, and the U.S., AI can only be of limited value until efficient systems of sheep recording and progeny and performance testing have been developed. At present flocks are so widely dispersed and operated with such small labor units, especially in Australia and the U.S., that the price in the market for products from sheep would have to expand to justify all that is required for multi-flock progeny testing.

Application of AI in the Warm Climates

Although AI is possible for cattle, sheep, swine, and buffaloes and has advantages for national programs, the question arises, when is it feasible and when is it not? Experiences thus far in countries of the N-S 30° area show evidence both for and against expansion of AI on a country wide basis.

India and Egypt have devoted a great deal of effort and resources to development of country wide programs for AI with cattle and buffaloes. To date little information has been made available on the value of these programs for genetic improvement of stocks. Some improvement may have been realized, but for the funds invested the returns have no doubt been exceedingly small, principally because of the low selection differential in choosing the sires, the poor levels of nutrition in the herds, and the limited extent to which AI has reached into local areas. Few efforts have been made to collect information on progeny, and consequently all the sires for AI service have come from a narrow base of small herds on government farms or a few imported sires.

Other countries, notably Iran, have attempted to center country wide AI programs for dairy production on imported bulls, with some supplementation of sires from small herds of imports. Because of inadequate means of communications, small number of sires available, and very limited record keeping, the returns on investments have been disappointing. As indicated in Chapter 10, AI was accepted in Iran reasonably well in the beginning stages due to high acceptability of the first generation crossbreds, but its popularity declined with the less desirable performance of crosses with more than 50% European breeding.

If the AI programs in the three countries mentioned are judged on an economic scale, the returns are disappointing. But if they are

judged from the standpoint of their contribution to needs for social and political viability the end results look somewhat different

In contrast to the questionable success of AI programs of India, Egypt, and Iran, there are, according to published reports, quite successful AI programs for dairy cattle operating in Kenya, Uganda, Brazil, Colombia, Venezuela, Costa Rica, Jamaica, Mexico, and Queensland, Australia And Israel has a very efficient AI program. AI is used in about 40% of the dairy herds in Puerto Rico. Why has AI been more successful in some places than others? Except for Israel, the better experiences are generally attributable to concentration on offering service to limited areas instead of broad coverage and emphasis on supplying herds where managers have well above average appreciation of the potential benefits of AI

There are many areas in which AI should be considered an essential tool in improving livestock performance, particularly with cattle At the same time, AI will not miraculously alter the underlying difficulties of production, therefore, it can succeed only where it will serve as an integral part of improved general husbandry practices Another prerequisite is that the sires must have higher genetic potential than many of those used in the past. Performance testing should, in most instances, be a part of the AI program Finally, irrespective of the genetic merit of the sires for AI, satisfactory levels of fertility must be obtained or else there will be limited acceptance by farmers At present it does not appear that country wide programs should be considered for swine, sheep, or beef production, but some programs may be useful on a limited scale

AI development should start with programs that will yield returns to the livestock industry rather than broad area coverage which is very costly AI could be used for planned matings in selected herds of flocks to produce either pure or crossbred sires for distribution on a broader basis It might also be useful in those same herds to provide a progeny test to intensify further selections before using a few sires to produce a sizable number of sons AI may afford advantages internally in certain large herds thoroughly expanded use of some sires Where there is a concentration of stock, especially in dairy operations around urban centers, AI could be supported and used effectively, particularly for larger farms whose feeding levels are adequate but whose bulls are of inadequate standards

AI is not feasible where nutritional levels are low, disease problems are serious, facilities and labor are restricted, operations are widely dispersed, or there is distrust on the part of intended recipients The need for genetic improvement in these areas is great, but until management is improved the genetic impact of AI will go

unrecognized. In fact, introduction of AI would be a disservice, especially if imported stock were used.

When grading-up programs are designed to utilize importations of semen, it is desirable that the quality of sires from whence the semen comes be as high as possible. This should lead to the selection of progeny tested sires of well above average merit. For Holstein sires from the U.S., for example, we would like the sires to have an estimated predicted difference of +250 kg or more of milk and the estimated repeatability of the proof to be 70% or higher. Such sires are in great demand; accordingly, the premium prices placed on the semen make their use unfeasible for broad area breeding schemes. They can only be afforded for planned matings to provide sires for future service in local areas. Using a cross section of sires in a given group is less expensive than using premium sires but still rather expensive for general use. The least expensive imported semen would be that of "young selected sires" that have been chosen for sampling by AI studs. Since the demand for these sires is limited in relation to supplies of semen, the cost would be lower than for progeny tested sires. Use of a sizable number of these sires would give 60–80% of the expected genetic progress in comparison to average sires and about 50% of the gain expected from the very highest sires. Until countries are in the position to establish their own progeny testing programs, the use of a large number of "selected young sires" makes AI more feasible.

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13

Management in Relation to Animal Health

Animal health requires the livestock operator's constant attention In all environments, health problems cause great losses in livestock production. For the U S , the estimated annual losses of cattle, sheep, swine, and poultry, and their products, from infectious and noninfectious diseases are more than 1 5 billion dollars Losses from parasites add approximately another 330 million dollars These losses, not including the costs of drugs and treatment, are equivalent to over 11% of the total income from livestock and livestock products Although losses in the U S are rather high, losses in the warm climates, figured on the basis of per animal marketed, are much worse

Often those who maintain livestock in the warm climates accept the idea that problems from disease and parasites are inevitable, but this notion must be rejected insofar as possible since healthy animals are essential for economical livestock production The maintenance of healthy animals in any environment requires the support of professional veterinarians, who can treat clinical cases of disease and assist in eradication programs However, the day-to-day health disturbances, which account for the greatest losses in animals and performance, must be attended largely by the manager In many areas

the wits of the livestockman is the key factor in managing all types of animal health problems due to insufficient veterinarians. For example, there are less than 3,000 veterinarians in all of Africa. More than ½ of these are in two countries, Egypt and South Africa.

No attempt can be made here to cover the details of the pathology of tropical diseases, disease symptoms, and extensive control procedures. Standard texts on animal diseases, such as those listed at the end of the chapter, should be consulted. FAO, WHO, and OIE are international agencies that support research on animal diseases and attempt to coordinate programs on identification of diseases as well as control methods. Periodic reports are issued by each agency, such as those listed among the references. FAO also issues annually an "Animal Health Yearbook," which serves as a ready reference to the diseases present in almost all countries and the probable extent of infection.

The losses of livestock and their products from health breakdowns are generally divided into two classes: mortality and morbidity. The definition of the first is obvious. The second applies to reduced yields and depreciation of animal products through such causes as destruction of parts of carcasses due to injury, disease, or parasites; reduced quality of meat, hides, and wool resulting from insects or poor slaughtering procedures; lowered resistance of stock to diseases because of poor nutrition; wasted feed and labor attributable to subclinical conditions of disease and parasites; inefficient use of pastures, shelters, and other facilities by unproductive stock; and expenditures for worthless or inefficient drugs, treatments, and equipment. In most areas of the world annual losses from mortality usually represent less than 5% of the total gross income from livestock enterprises; whereas, morbidity losses are several times larger, especially in the warm climates. The skill of the manager is the principal factor in minimizing morbidity losses.

Another important reason for minimizing livestock diseases and parasites is the danger of zoonoses—diseases that can be transmitted from animals to man. Of more than 200 communicable diseases of animals, about one-half are considered infectious to man and more than 80 are transmitted naturally between vertebrate animals and man. Some of the more common ones are undulent fever, tuberculosis, cowpox, ringworm, rabies, and anthrax. In certain areas trypanosomiasis and equine encephalomyelitis also threaten human health. In addition, man is susceptible to many of the same parasites, as animals, including hookworm, roundworm, tapeworm, and flukes. Although livestock constitute reservoirs of diseases and parasites affecting man, wild animals and rodents are more hazardous than domestic ani-

mals For instance, rats and mice are historically the most important sources of zoonoses (Schwabe, 1969)

CAUSES OF BREAKDOWNS IN ANIMAL HEALTH

Breakdowns in animal health are generally due, either directly or indirectly, to one of five major causes (1) Abnormalities and disorders of non infective nature that are inherent in the animal. These may or may not be recognized depending upon the environmental conditions (See Chapter 9), (2) infectious agents, such as viruses, bacteria, and rickettsia, which may affect an animal at any stage of life, (3) ecto- and endo-parasites, which are a consistent hazard in almost all environments, (4) non-infectious conditions, such as nutritional disorders, bloat, milk fever, or mineral and vitamin deficiencies, that can become problems in all environments at any stage of the animal's life, and (5) accidents, such as falls, cuts and abrasions which besides affecting the animal's health directly, may make the animal more susceptible to diseases.

Infectious Agents

Basically, infectious agents fall into two classifications pathogens, including viruses, and protozoa Either type can have debilitating effects In the lowland tropics of Latin America, for instance, the pathogenic diseases, aftosa, vesicular stomatitis, rabies, hog cholera, anthrax, blackleg, and equine encephalomyelitis, all have an economic impact on livestock production Of these, aftosa and vesicular stomatitis are most significant An attack of either disease in late gestation may cause the animal to abort, and a clinical case in early stages of lactation may reduce milk flow to the point that the suckling calf dies of starvation The side effects of aftosa may be worse than the infection itself In India and elsewhere it has been observed that following an attack of this disease European breeds of cattle or crossbreds with more than 60% European breeding show lower tolerance to heat and other stresses The reason has not been determined, but since aftosa primarily affects epithelial structures of the skin, it probably reduces moisture transmission, thus depriving the animal of an important cooling device for a hot environment

In terms of total impact on the cattle economy throughout the

world, aftosa is probably the most harmful disease. Where the disease is prevalent death losses are only about 5% but the morbidity effects are high through loss of milk, growth and abortions. Currently only five countries are considered free of aftosa: Canada, the U.S., Mexico, New Zealand, and Australia. The disease has spread through other countries to varying degrees, depending upon control measures. Few countries have systematic campaigns of vaccination. Argentina, Venezuela, and Costa Rica claim to have vaccinal protection for up to 80% of the bovine population. But in other countries, vaccination does not reach more than 40%, and as a result epizootic waves are not uncommon. Vaccination is less widely used in beef herds than in dairy herds because the vaccines in current use are effective for only 4 to 6 months. This is another reason for lack of use in extensive beef operations. Other vaccines under field test appear to hold more promise since they are effective for 9 to 12 months or even longer.

Although the main losses from diseases like aftosa or rinderpest are classed as morbidity, others, such as rabies and anthrax, result in high mortality. According to FAO data (FAO, 1968), rabies accounts for the death of more than 50 thousand cattle per year in Latin American countries.

Some of the other more serious pathogenic diseases in warm climates are tuberculosis, brucellosis, and swine atrophic rhinitis. The most desirable control for these diseases is eradication by slaughter or vaccination, but this must be done on a wide basis to be very effective. The individual herd or flock owner usually must resort to isolation or exclusion of contact of infected animals, slaughter, sanitation, vaccination, induced or acquired immunity or control through prophylactic feeding of antibiotics (Br. Vet. Assoc., 1962).

Vaccination has great appeal, but unfortunately few pathogenic diseases can be effectively controlled through vaccination. Some of those for which good control are claimed, at least in some areas, include blackleg, anthrax, brucellosis, hog cholera, Redwater, tetanus, and hemorrhagic septicema. Vaccination has met with limited success for rabies, leptospirosis, equine encephalomyelitis, coccidiosis, and mastitis, as well as numerous other diseases. Though vaccination is successful or partially successful for only a few pathogenic diseases, it would obviously be more effective if mass inoculations could be made within a short period and continued on a routine basis. But the impracticability of this approach often defeats vaccination programs. Another problem is getting a vaccine that will be effective against all the pathogenic types of a disease. For instance, an anthrax vaccine used in the northern part of the U.S. is not suitable against strains occurring in the deep south. The inadequacy of trained

manpower and the expense of getting the programs carried out further restrict control by vaccination

When to use and not to use vaccination rests to a degree on the decision of the manager but his role is frequently more critical in control through other means Isolation is usually effective if the infected animal or animals are readily quarantined, since most pathogenic diseases are transmitted through animal contact Slaughter is another means of arresting the spread of disease Sanitation is important too, particularly where animal shelters and other facilities are involved Prophylactic treatment with antibiotics to control pathogenic organisms has become standard practice in swine and poultry enterprises Many of the rations employed for young dairy calf feeding include antibiotics for the same reason Due to the expense, antibiotic feeding is not recommended for adult animals except as an emergency measure to prevent spread of infection

Some pathogenic diseases may leave animals with temporary or permanent immunity against further attack An attack of East Coast fever builds permanent immunity, while brucellosis and aftosa are two examples where temporary immunity may arise Temporary immunity may also result from an intra uterine transfer of antibodies or transfer of antibodies to the young through the dam's milk Induced immunity is not generally recommended, but from a practical standpoint it may sometimes serve as a buffer against serious losses Some livestockmen prefer not to use vaccination for the control of brucellosis or aftosa, especially if the disease remains in the general vicinity of the farm, because they feel that the risk of mortality from an outbreak among highly susceptible animals outweighs the risk of morbidity effects from a few clinical cases

Test and slaughter are used to control tuberculosis Most countries have health laws requiring this practice But for various reasons the programs are not really effective, and thus tuberculosis remains a threat to both human and animal health throughout the warm climate regions

Brucellosis can generally be controlled through vaccination For best results it is recommended that cattle be vaccinated between 4 and 9 months of age Here too, general control is much less than desired due to inadequacies of systematic programs of vaccination carried by many countries

Rinderpest is confined principally to southeast Asia and Africa. Until recent years rinderpest was the most serious livestock disease in India, but a nationwide program of vaccination has been gradually reducing its incidence

Protozoa Diseases

Some examples of protozoa diseases are anaplasmosis, Redwater, East Coast fever, and trypanosomiasis. These diseases may or may not cause high mortality among cattle. Losses depend upon animal susceptibility, age, stage of lactation or gestation, and nutritive state. They all require an intermediate host since there is little opportunity for the protozoa to be transmitted through animal contact. Ticks are the most frequent hosts for anaplasmosis and Redwater; however, mosquitoes, horseflies, and other biting insects may serve as mechanical transmitters. The tsetse fly is the primary transmitter of trypanosomiasis, and a microparasite (*Theleria parva*) carried by the brown tick (*Rhipicephalus appendiculatus*) causes East Coast fever. Losses from these diseases can be quite high, as illustrated in Table 13.1. In this dairy herd in southern Louisiana, the clinical cases and deaths accounted for the losses of milk; the total estimated losses in income were 12.1% of gross income in 1964 and 6.9% in 1965.

Protozoa diseases may hit a farm hard one year and then decline until the susceptibility of the animals rises again. When susceptibility is high a recurring outbreak may occur later as illustrated in Table 13.2. In this herd there was a high number of clinical cases in 1956 followed by a low incidence of both death and clinical cases until 1964. The decline in percentage of reactors after 1960 shows that susceptibility of the herd rose. By the end of 1963, 77% of the animals showed no titers for anaplasmosis. The high level of susceptibility at this point probably led to the severe outbreak in 1964 and the resulting 47 clinical cases and 6 deaths in 1964 (Table 13.2).

Up to this point vaccination has not proven very effective against protozoa diseases. Several vaccines have been tested for anaplas-

TABLE 13.1
Estimated losses ($US) in income from a dairy herd infected with anaplasmosis.

	1964		*1965*	
	Loss	*Value*	*Loss*	*Value*
Salable milk	58,000 kg	$7,600	27,000 kg	$3,600
Animals				
Cows	6	1,500	5	1,250
Calves	5	50	0	
Veterinary fees		524		642
Percent of gross income	12.1		6.9	

TABLE 13 2
Mortality, frequency of clinical cases, and reactors or carriers for anaplasmosis by years in a dairy herd in Louisiana Herd size ranged from 106 in 1956 to 195 in 1966

Year	Number of clinical cases	Deaths	% Reactors
1956	29	3	59
1957	3	0	39
1958	7	0	54
1959	5	3	55
1960	1	0	44
1961	6	0	38
1962	13	3	26
1963	9	2	23
1964	47	6	52
1965	9	5	35
1966	7	3	31

mosis but without acceptable results These were largely killed vaccines Currently there are several other vaccines under test for anaplasmosis Also the feasibility of a vaccine for East Coast fever also looks promising Of course, vector eradication or control always helps

Since vaccination for anaplasmosis is rather ineffective, development of the "carrier state" is often the most practical means of minimizing serious losses—unless of course, there is a wide area eradication or clean up program In Louisiana, all other factors being equal, a bull from an anaplasmosis infected herd will sell at a higher price than one from a clean herd because of the prevalence of the disease in the area and the probability that the bull has acquired some natural immunity At an experiment station in northern Colombia, newborn calves were removed some distance from their mothers at birth for rearing but later when they rejoined the herd at 10 to 12 months of age losses from anaplasmosis were high because through isolation the heifers had become highly susceptible When the calves were kept in the proximity of older animals the number of clinical cases in young calves and heifers was much less At present there are no countries in the N-S 30° latitudes with effective control programs for anaplasmosis —including the U S

The diseases described above may cause very serious losses when the incidence of infection is high But in many situations herd or flock losses, both as morbidity and mortality, result from what might be classed as "minor infections" or nutritional disorders Scours (in-

TABLE 13.3
Diagnosis and treatment of health disorders of cattle in ten veterinary clinics in Colombia in 1959.

Health problem	*Percent of total treatments*
Aftosa (vaccination breakdowns)	22.0
Enteritis (other than calf scours)	13.6
Scours, simple	13.3
Scours, infectious	7.3
Dictyocaulus (lung worm)	5.9
Mastitis	3.9
Bloat	2.9
Anaplasmosis	2.6
Physical injury	2.2
Screwworm	1.6
Intoxications (various)	1.5
Retained placenta	1.4
Metritis	1.3
Pneumonia	1.2
Coccidiosis	1.0
Other (60)	18.2

Source Adapted from *Rockefeller Foundation Report, 1959–60*

fectious or noninfectious type), pneumonia, bronchitis, diarrhea, ringworm, pinkeye, and foot rot very often are the major causes of losses in young animals, not only through death but also through retarded development and increased susceptibility to disease in later life. There is evidence that a calf that has scours or pneumonia has a three times greater chance of serious health problems in later stages of life than a healthy calf. A calf that loses a portion of its effective lung capacity due to an attack of scours, pneumonia, or bronchitis will often be almost worthless as a lactating animal. This is particularly true in the warm climates where temperature stress requires good lung capacity for respiratory cooling.

In lactating cows, such conditions as mastitis, metritis, foot rot, milk fever, diarrhea, dystocia, and physical injuries are at least as damaging economically as major infectious conditions. In India, where rinderpest and aftosa are prevalent, the rate of removal or death in one large herd was over five times higher for mastitis than for aftosa. Similar observations have been made in Colombia. In areas where the prevalance of aftosa and anaplasmosis was high, treatments in both dairy and beef herds for these two diseases accounted for only 25% of all veterinary treatments in 10 veterinary clinics (Table 13.3). Other

infections and nutritional disorders accounted for the majority of breakdowns

Diseases such as anthrax or hog cholera can destroy a herd or flock, but the so-called minor diseases and noninfectious disorders are frequently of greatest economic significance on a continuing basis

Non-infectious Diseases

The greatest losses from non-infectious diseases, such as nutritional disorders, are due to faulty feeding and management For instance, of all the pigs born in the U S , approximately 25% are not reared to marketable age This amounts to about 6% of the total dollar value in production These losses are due to chilling, failure to nurse, injury and death directly traceable to the sow, and various forms of enteritis caused by infectious or nutritional factors From a survey of the beef cattle industry in the U S it was estimated that 8–10% of all cattle were sick annually from one or more nutritional disorders (Ensminger *et al*, 1955)

Although chilling is often not recognized as a problem in tropical areas, indirectly it is the major cause of death among pigs, lambs, and calves High temperatures may aggravate an illness in the newborn, due to hastening of dehydration, but the lower temperatures at night, coupled with high humidities, make animals more susceptible to health problems Even in the warm climate of the coastal region of Puerto Rico neonatal pig losses were markedly reduced by the use of heat lamps, and somewhat reduced by the use of burlap screens over the openings in the walls

Faulty nutrition can be just as much or more of a problem in warm climates as in temperate areas even though the level of feeding may be lower For example, rancid oil cake, even when fed in small amounts, can create serious disturbances Poor sanitation is probably the greatest cause as residual feeds left in a manger will often ferment after several hours, resulting in problems of toxicity

On either drylot feeding or grazing, deficiencies of minerals, such as phosphorus and iodine, or excesses of fluorine or selenium may be just as debilitating to livestock as any infectious disease In certain areas the development of urinary calculi in sheep may seriously impair performance Bloat, milk fever, acetonemia, and grass staggers are all considered nutritional diseases Also of significance in a number of areas is the hazard to health or death from animals grazing poisonous plants (see Chapter 6)

Internal Parasites

There are about 300 kinds of internal parasites of economic significance in the U.S., and there may be up to 10 times this number for the world. Parasitism exists primarily subclinically and, therefore, brings about unnoticed economic losses. This is largely because where infestations occur, parasitism is essentially a herd or flock disease rather than of the individual animal. Hence, measures to control parasites are effective only if applied to the whole herd or flock as though it were a single animal. It requires the judicious use of feasible, profitable measures to minimize the losses and hazards of parasitism. Eradication of most parasitic infestations is usually unfeasible in practice, if not impossible and perhaps even undesirable. Sanitation, along with medication, appears the most effective measures for control.

The common worm parasites are broadly classified into roundworms or nematodes, flukes or trematodes, and tapeworms or cestodes. Unlike bacteria, worm parasites do not multiply within the animal; thus the number found in an animal is related to the number taken into the body. Animals become infected with roundworms principally by grazing contaminated pastures. After ingestion, the female roundworms deposit eggs in the stomach and intestines. These are passed from the host through the feces. Unless the droppings are exposed to sufficient sunlight for rapid drying, the eggs hatch into free-living larvae. With favorable temperatures (about 26 to 30°C), and moisture (65% relative humidity), the larvae develop into infective stage larvae in about 2 or more weeks, depending on the species. The larvae migrate onto the grass where they are picked up by the grazing animal to complete the cycle.

Flukes, especially liver flukes, are a problem in lowland areas of warm climates. For instance, about 75% of all livers of cattle processed in slaughterhouses from herds in low lying areas of Puerto Rico are condemned. Chemical treatment can be effective, but fencing off or drainage of swampy areas is the best means of maintaining control.

Tapeworms behave in much the same fashion as roundworms with respect to life cycle and transmission.

Although all three types of worms are capable of killing cattle or sheep, their effects on the hosts are very difficult to evaluate. By the time the secondary effects—e.g., shaggy hair coat, drooping ears, extension of the neck and head when standing, or extreme emaciation—are evident, the chances of the animal returning to normal performance are rather slim. Parasites rob the animal of nutrients and do harm

to vital organs They also make them more susceptible to infection by bacteria or other disease producing agents And the migration of developing parasitic worms through organs and tissues interferes with normal body functions, resulting in poor utilization of pastures, labor, and space (Ciordia, 1969)

Factors conducive to parasitism are warm, humid climates heavy stocking rates, overgrazing, inadequate feed or low levels of feeding, moving animals in from another area that have not been previously exposed to parasites, grazing animals of varying ages simultaneously on the same pasture, poor sanitary conditions around shelters, and a low state of general health The control of parasitic infections is principally a problem of livestock and land management to break the life cycle of the parasite Treatment of host animals with chemicals is therapeutic but not of great help in prevention Parasites are most vulnerable during the egg or larva stage

Under grazing conditions, contamination can be prevented or eliminated through such practices as light stocking, resting and rotation of grazing, herd separation, and sometimes chemical disinfection The season at which animals are marketed can influence the level of infestation Parasites are usually most prevalent near the end of the rainy season For this reason sale of older animals and removal of young stock to cleaner areas helps in control The length of the dry season is also a factor in the control of parasites

There is evidence that immunity to internal parasites can be built up in animals If young animals are not exposed to a large number of larvae, they will become partially immunized and have fewer worms later Very young animals have few parasites even on infected pastures After 2 or 3 months, infestation in calves may increase rapidly up to about 9 months of age and more slowly thereafter At about 18 months of age the incidence of worms tends to decrease In many warm, humid areas, young calves may be reared on concrete floors with good sanitary control and then suddenly they are placed on an infested pasture If at this time the animals are expected to obtain their feed from grazing, the pick up of parasites will be very rapid, and frequently with toxic effects When such quick transitions are made, continuation of concentrate feeding is recommended to lessen the buildup of parasites

Since the eggs and larvae of parasites are found in the animal droppings, efforts should be made to prevent the accumulation of droppings in housing and around watering places When control through prevention is not practical, the animals should be treated with anthelmintic drugs However, treatment alone should not be relied upon to prevent outbreaks or to cure weakened animals Anthel-

mintics are most efficient when used as an adjunct to other control measures. Phenothiazine, given by drench or in concentrate feeds, has long been the principal drug for treatment of ruminants. It is preferable to use it as drench to insure that each animal gets the recommended dosage. This is because control with ingestion through feeding has not met with much success. Twenty grams per 50 kg body weight is recommended up to a maximum of 60 grams per treatment. A disadvantage of phenothiazine is that it does not work well against a number of parasites.

Organo-phosphorus compounds have been tested as anthelmintics in cattle and sheep. They are effective but toxicity to the animal restricts their use. Thibenzole is the drug currently preferred. Successful results with this compound have been obtained in Argentina, Brazil, South Africa, Venezuela, Britain, and the U.S. It is active against many parasites in a wide range of hosts, works on immature worms as well as adults, and is well tolerated by the host. Like phenothiazine it is used as a drench at the rate of 5 grams per 50 kg body weight. L-Tetramisole (Tramisol) and parbendazole are two other drugs that have given good results. Sodium fluoride is frequently used for control of roundworms in swine. Antibiotics—e.g., aureomycin and terramycin—have also been employed for pigs and calves, but the dosages required are prohibitive in cost for adult cattle. Vaccines made from killed larvae have been tried, but so far they have not been widely accepted. Treatment with drugs is usually at 3 to 6 week intervals depending upon the infection.

Some claim that anthelmintics should not be used at all, arguing that healthy animals can cope with some infestation of helminths, thus they are capable of keeping the level of parasitism in check. The premise is that treatment would make the animals more susceptible. Such may work if precautionary control measures are practiced. Other arguments against treatment are that once it is started it must be continued to avoid reinfestation and that treatment of animals under extensive grazing conditions is impractical, especially since animals on extensive grazing continuously are not nearly as likely to have serious parasite problems. These are valid arguments and may prove satisfactory in some instances. On the other hand, in many areas treatment to reduce infestation plus measures for control are most practical.

Treatment of emaciated animals with drugs is not wise unless there is good evidence that parasites exist. Drugs given at the recommended dosages can be highly toxic to very undernourished animals. Before treatment, it would be wise to put such animals on better feeding to prevent toxicity and perhaps death. Even though low levels of feeding are conducive to problems of internal parasites, it should be

kept in mind that on good grazing the problems may be equal or greater Also, since the application of fertilizers and the use of improved species of grasses permit higher stocking rates, these actions may increase the incidence of internal parasites

External Parasites

External, or arthropod, parasites impair the maximum efficiency of livestock as a nuisance They may serve as transmitters of disease and decrease the quality of livestock products There are several thousand species, but less than one hundred are considered hindrances to livestock production Economic losses from arthropods are usually high in the warm climates—more from morbidity than mortality, unless the parasite transmits a disease Morbidity losses are principally from reduced feeding, resulting in reduced rate of gain Cattle treated to control horn flies have gained 5 to 20 kg more per month on pasture than nontreated contemporaries

The need for protecting livestock against arthropods is recognized even under the most primitive systems of livestock keeping It is common practice among some groups in Africa to put their cattle under a shade for protection against the midday sun While there, smoke is provided to curtail annoyance from flies Indian villagers keep their dung cake fires going well into the night to help keep mosquitoes away from their cattle Children are frequently assigned the task of washing or dousing the livestock with water during the day to repel insects as well as to cool the animals

Many kinds of arthropods suck the blood of animals while others destroy body tissues The bloodsucking parasites are most numerous They include mosquitoes, gnats, flies, lice, and ticks The annoyance from mosquitoes and flies causes cattle on grazing to congregate and use the proximity of each other to aid in freeing themselves from the irritations of the insects, thus feeding time is decreased Some parasites may produce toxins, which are injected into the host during the process of piercing the skin to suck blood, these may create severe local skin reactions

Some arthropods are more adapted to temperate climates—e g, horseflies (*Tabanides* spp) and lice Horseflies are less prevalent in the tropics because ants feed on their larvae However, lice are considered one of the major problems for sheep in northern Australia. They also do damage to Angora goats in southern Asia. Poultry lice

are a worldwide phenomenon, creating especially serious problems among poultry in confined housing in the tropics. Insects such as lice, which live on the animal, are easier to control than flying insects.

Larvae of cattle grubs (*Dermatobia* spp.) cause damage to cattle hides. The adult female fly may deposit eggs on the hair coat of the animal or on other flies or mosquitoes, which transmit the eggs to the animal. If the eggs are laid on the surface of the animal, the larvae penetrate the skin and migrate through the animal's body eventually coming to rest along the dorsal surface. As soon as they reach this surface they open holes through the skin for respiration and eventually emerge through these openings as developed larvae. When they drop to the ground, they hatch and begin the cycle over. They are best controlled by dusting an insecticide on the back of the animal near the time they are expected to emerge.

There are several species of screwworm; one is prevalent in the Americas, another in Africa, and still another in Australia. All prefer to deposit their eggs on wounds and the larvae feed on the flesh until they are fully developed. Thousands of larvae may be in a wound after a few days. They will destroy tissue and consume blood and lymph until the animal dies. Biological control for screwworm has been effective in the southern U.S. and is now being attempted in other areas. This consists of releasing large numbers of laboratory reared, sterilized male flies during the peak of the mating season. The sterilized males, if released in large enough numbers, conduct most of the matings; thus it is possible to eradicate the flies after a few generations. Where screwworm is a serious problem, attention at calving is a good practice since dipping of the naval in an iodine solution quickly dries up the cord.

Fleeceworms are caused by flies similar to screwworms. They lay eggs on soiled wool of sheep. The larvae feed on the surface of the skin and cause severe annoyance. Like screwworms, fleeceworms can kill infested animals unless infestations are treated promptly.

Hornflies (buffalo flies) are blood suckers but they do not transmit disease. Nevertheless, heavy infestations will be a nuisance to the point of lowering production. These occur almost everywhere.

Midges (*Culicoides* spp.) transmit the virus for blue tongue. They are extremely small flies, breed in low lying, wet areas, and mainly affect sheep, although they attack cattle too.

There are many types of mosquitoes. Some are known to transmit Rift-Valley fever to sheep and cattle. In some areas they have been identified as a vector for anaplasmosis, not by passing the organisms

through their body, but by mechanical transfer of blood from one animal to another

The two major disease transmitting arthropods are the tsetse fly and the tick Africa has been known for its tsetse fly, which transmits surra and nagana, or trypanosomiasis, to cattle, horses, sheep, goats, and pigs, and African sleeping sickness to man There are more than 20 species of tsetse in tropical Africa. The species *Glossina* spp seems to be the most widespread These flies are principally daylight feeders but they will also bite on moonlight nights In the dry regions they persist in the vicinity of watering points However, they prefer more humid areas with tree or bush covering

The tsetse fly needs a blood meal at regular intervals and requires a resting area hence shows preference for trees or brush The larvae in the pupa stage requires shade and moisture The tsetse breeds slowly It has a simple but almost invulnerable life cycle of two stages —adult and larvae The adult lives for several months as a flying insect while the larva, in its pupa, is imbedded in moist soil or rotted plant material For all practical purposes, the larva pupa stages can be attacked only through the adult as the larvae do not feed

Control of tsetse requires area clearance to be effective This generally means that governmental assistance is needed Brush clearance, distration and removal of game and other hosts, and chemical means are the usual control methods DDT sprayed by aircraft at 3-week intervals has given 92% control in limited areas (WHO, 1964), but the general use of chemicals is prohibitively expensive Besides, the tsetse rapidly builds up resistance to chemicals Species that locate at water points (e g , *G tachinoides*) can be controlled by complete clearing of trees up to 2 km but unless the cleared area is at least 0 5 km wide, the flies use sight and movement to find hosts Trap insecticides and burning are also recommended for this species For the *G morsitans*, which prefer the savanna areas with patches of bush and moderate to heavy shade spraying is not very effective, therefore, control is brought about by bush clearing, destruction of wild animals, and regulation of human settlement.

Since tsetse flies feed primarily during the day, grazing at night and moving the animals to cleared areas in the day help Control of tsetse flies is involved and costly, so control measures will generally pay only under intensive farming systems The use of sterile males to control tsetse is attractive, but because of the tendency of adult flies to scatter it would be almost impossible to produce enough males for very far reaching control Eradication seems to be the answer, but how best to bring this about has not been resolved

The ability of ticks to transmit many diseases to their offspring by transovarian transmission is a principal reason why they are so detrimental. With this capability there is no need for each generation to pick up the disease(s) from infected hosts. There are many species of ticks, but about eight are the major disease transmitters. The blue tick (*Boophilus* spp.) is a carrier of Redwater and anaplasmosis; the red tick (*Rhipicephalus evertsi*) is a transmitter of Redwater, East Coast fever, and anaplasmosis; and the brown tick (*Rhipicephalus appendiculatus*) is a carrier of East Coast fever, anaplasmosis, Redwater, and Nairobi sheep disease. These three species are the worst offenders. They all attack cattle, sheep, goats, and horses.

Tick control consists of periodic dipping and spraying with insecticides. Toxaphane is an effective insecticide, but several insecticides must be used because ticks quickly build up resistance. Full plunge dipping is preferred since it gives the best coverage of the animal's body, but has the disadvantages of sanitation problems, requires a large volume of material, and increases the danger of injuries. In some countries, such as Uganda, dipping tanks are made only one meter in depth. This provides coverage of the lower body. As the animals emerge from the tank they are sprayed over the top. Such seems preferable from several standpoints to full plunge or spraying only. Dipping or spraying is recommended at 14 day intervals for one host ticks, 7 days for two host ticks, and 5 to 7 days for three host ticks. But these intervals should be halved when programs are being initiated to markedly reduce ticks and control transmission of disease. This becomes expensive. Treatment is more important at the beginning of the tick season for some species because it is easier to control the number of off season ticks before reproduction builds up the numbers and both stages—on and off the animals—are occurring.

Ticks with more than one host are harder to control because they spend only part of the time on the domestic animals and exist in reserve numbers on uncontrolled secondary hosts. These ticks are particularly hard to control while on small ground animals. Unlike tsetse flies, ticks are limited in their range and movement by the hosts themselves.

In Australia, management practices have drastically reduced the number of blue ticks, thereby lessening the need for regular dipping. The recommendations were based on the unfavorable conditions for the immature or seed ticks from the time the eggs are laid until attachment on the animal. By using pasture spelling, livestock operators destocked long enough so that most of the immature ticks died without finding a host (CSIRO, 1959). The resting period of the pasture

TABLE 13 4
Some agents for control of external parasites

Compound	*Parasites*
Aldrin	Cattle grub, screwworm, lice
Bayer 13/59	Cattle grub, screwworm, lice
BHC	Lice, mites ticks, sheep ked
BHC and DDT	Ticks
Chloradane	Lice ticks, fleas, mange
Chlorothion	Cattle grub, screwworm, lice
Diazinon	Woll maggots, sheep keds lice
Dieldrin	Cattle grub, screwworm, lice
DDT	Hornflies, lice, fleas
DDT and lindane	Ticks
EQ 335	Screwworm
Heptachlor	Cattle grub, screwworm, lice
Malathion	Cattle grub screwworm lice
Methoxychlor	Hornflies, lice fleas
Perthane	Cattle grub screwworm lice
Pyrethrum	Paralytic for most biting insects
Rotenone	Cattle grub lice fleas
Strobane	Cattle grub screwworm lice
Toxaphane	Variety of pests including ticks

must be 3 to 4 months for this program to be effective The customary 2- to 3-week rotational grazing pattern will contribute little to tick control The animals should, of course, be redipped before returning to a rested pasture Burning of grasslands can also be used at times as and aid in tick control

Table 13 4 lists some agents recommended for the control of ticks and other arthropods, along with the species they may be employed against

The vampire bat (*Desmodus rufus*) is not an arthropod, but it feeds on the blood of animals and man and transmits rabies In some of the lowland areas of Latin America, cattle cannot be left in the open at night because bats will attack them as they are resting The bats prefer the soft areas of skin around the vulva and the udder Once the skin is broken the bats gnaw the flesh to open up large wounds, which permit infections or introduction of rabies European breeds of cattle seem more susceptible to attack than Zebu or local Criollo types

In warm, humid areas wounds heal slowly lengthening the animals' susceptibility to infections, introduction of flies of the screwworm type and others as well as attacks by bats However, ticks will

not usually invade a wound; they prefer to make their own penetrations through the skin.

Photosensitization is a disease usually associated with exposure to sunlight. But porphyrinemia (porphyrins in the blood) and toxins from plants and biting parasites can also result in photosensitization. Animals with light pigmented skin are most susceptible. There is some evidence of an inherited susceptibility in Southdown sheep, cattle, and pigs. The condition causes the epidermal layers of the skin to become encrusted; the outer skin and hair coat slough off to the point that the animal may die from exposure of the dermal layers and loss of body fluids. This disease is fairly rare among livestock indigenous to the tropics. European breeds of cattle with non-pigmented skin and white pigs, such as Landrace or Yorkshire, are most susceptible. If recognized in time the condition may be arrested by sheltering the animal from the sun. But once the condition occurs, the animal will probably repeat if exposed to sunlight.

SUSCEPTIBILITY TO DISEASE

Although there is little evidence of direct genetic resistance to disease, immunity to a disease process may be built up in certain animals to an appreciable extent through contact with limited amounts of infection. The contact may be either natural (e.g., through feeding) or artificial (e.g., through vaccination). Most of the resistance shown by various breeds to certain diseases is probably due to the intrauterine environment. This seems to explain the resistance to anaplasmosis, vesicular stomatis, East Coast fever and, to a lesser extent, foot and mouth disease. Also as pointed out in Chapter 9, the characteristic skin and hair coat of cattle are important indirectly for susceptibility to the invasion of disease organisms.

Another factor that may play a role in resistance is the ability of animals to develop their immunological defense mechanisms at an early age. The thymus gland seems to play an important role in such development. There is evidence from mice, man, and cattle that there may be inherent individual and breed differences in the ability to build up defenses against later invasions by disease organisms. If this is true, it may be that indigenous stocks show more immunity to disease because of the selective breeding resulting from the pressures of the tropical environment.

Swine are probably susceptible to a greater number of diseases than other domestic livestock and many more of these diseases are transmissible to man. Sheep and goats are susceptible to nearly all of

the diseases that afflict cattle, as well as a few are peculiar to their species Thus, for most environments, no one species seems to have a marked advantage over the others in resistance to disease.

Age seems to be a major factor in susceptibility, with the very young and very old having the least tolerance. Cattle show the greatest resistance to disease between 1 and 4 years, the period between 1 and 2 years being best. This has been clearly demonstrated in the transfer of cattle from temperate to tropical areas It is recommended that cattle be under 2 years of age when introduced into an anaplasmosis area and that the introduction be made at the lowest vector season

Age also is a factor in nonspecific resistance to stress Baby pigs under 2 weeks of age suffering from transmissible gastroenteritis may have 90–100% mortality, whereas mature swine suffering from the same disease, may have under 1% mortality

Animals in good condition are generally more resistant to infections Nevertheless, susceptibility can be increased in any animal from overwork, faulty nutrition, heat, cold, high humidity, air movement, and poor sanitation

Most countries have restrictions on the movement of animals designed to keep highly susceptible animals from exposure to diseases for which they have no immunity The restrictions sometimes involve traffic within the country, but more often they are concerned with regulating animals coming into the country Countries of the temperate zone generally have very stringent regulations, especially for animals coming in from tropical areas But the restrictions imposed by many tropical countries are not nearly as well defined nor as limiting on health requirements for newly introduced animals To date, we are not aware of many serious disease epidemics arising among stocks in the tropics from outside animals, but some diseases, such as New Castle disease, have become prevalent after introductions of poultry from temperate areas

More disease problems may arise in the tropics in the future as the result of livestock importation There is some evidence now, for example, that Johne's disease, or paratuberculosis, may be spreading among sheep in areas of the Middle East The disease had not been identified in the area before importation began Johne's occurs in several areas of the U S , but it frequently goes unrecognized because the symptoms are similar to those of parasitism, molybdenosis, and malnutrition At present there is no routine herd or flock testing required Infected animals may go out of the area without recognition Incubation of the disease may require years in the new environment. If infected animals have been used in a seedstock herd or flock, ani-

mals capable of transmitting Johne's may be widely dispersed among the local herds.

The potential of the spread of a disease like Johne's among a susceptible animal population illustrates the need for precaution in bringing new animals into a herd or flock, no matter the source. An organism to which one herd is immune could go rampant through another herd nearby. Clearly, all new animals should be tested insofar as possible before purchase and, when brought on the farm premises, isolated from the other animals and closely observed before being allowed to come into contact with the others.

HEALTH PROBLEMS IN INTENSIVE ENTERPRISES

Rearing in close confinement in poultry and swine units has increased production efficiency but this system has also presented new health problems. These problems may result from high airborne infections, more frequent contact, poor sanitation, and perhaps lowered resistance caused by an above average concentration of ammonia in the air. Similar problems occur in cattle confined to small lots for fattening or in concentrated dairy operations. Animal health problems fostered by close confinement are foot rot, mastitis, diarrhea, vesicular stomatitis, aftosa, leptospirosis, mycobacterial skin lesions, various skin diseases, external parasites, intestinal disorders and coccidiosis. High standards of sanitation are required at all times to keep outbreaks of some of these health disorders from going rampant through a herd. During the wet season, however, high standards of sanitation are very difficult to maintain; consequently, the likeliness of disease is great.

If young dairy calves are penned together, constant attention is required to prevent rapid spread of diseases. This is the main reason for the recommendation that young calves be kept in individual pens for at least the first month. Meticulous sanitation, adequate nutrition, and perhaps disease prophylaxis are required to minimize health problems among artificially reared calves.

SANITATION

Sanitation has been mentioned repeatedly as a means of minimizing health problems. Ultimately, it is the most effective method for controlling disease. But few people really know what constitutes good

sanitation In order for sanitation to be effective in livestock enterprises, one must know what proper cleaning is, why it is important, and how it can be accomplished effectively

The only reliable means of destroying disease organisms and parasites in certain stages is cleaning and disinfecting But the latter has little effectiveness unless the surface is first cleaned The best cleanser and disinfectant depend upon the type of surface Lye, caustic soda, creosol, and chlorine compounds are most commonly employed, along with liberal applications of water and detergents for cleaning No matter how primitive the situation, there are usually some means of maintaining reasonably good sanitary standards Compounds that are available almost everywhere are lime and some form of oil products Kerosene or diesel fuel may be used as an effective spray to control lice in and around a livestock shelter and they may be used on the ground or bodies of water to prevent emergence of insect larvae Sunshine is another very effective agent, and even changing the earth in certain situations has proven helpful The latter procedure is standard practice in Egypt as a means of maintaining good herd health as well as making the most efficient use of animal waste for soil fertility

Usually some relatively cheap disinfectant is available, which, if properly employed in conjunction with cleaning, will be effective against many of the major health problems Good sanitation practices also enhance the value of therapeutic agents The Merck Veterinary Manual (Schwabe, 1969) and similar publications are good resources for recommendations on sanitizing, therapeutic agents, treatment procedures, and identification of disease conditions

Livestockmen are aware of at least some of their unrealized income from animal health problems, and they respond to economic incentives They are generally receptive to guidance on alleviating breakdowns in animal health Consequently, program planners for livestock development frequently make some measure(s) of disease and parasite control a feature of governmental assistance

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14

General Management Considerations

Oftentimes substantial improvements in livestock performance can be realized through planning, especially with respect to matching projected feed supplies to animal needs, and to protection of animals from the extremes of the environment. The ensuing discussion deals with management of feed resources and means of reducing the impact of the usual physical environment of warm climates on livestock.

PLANNING A FEED BUDGET

A feed budget consists of planning ahead on feed resources. It usually has one of two objectives: (1) the provision of nutritive requirements for a predetermined number of livestock over a one year period or longer, or (2) the most efficient use of already available feed resources. An operator may have 50 cows which he expects to calve during a certain season; he anticipates weaning the calves at a given time and at a minimum body weight. Or he may have a dairy herd and hopes to produce a certain amount of milk per day. On the other hand, an operator may have an area for grazing that he wants to convert as effi-

TABLE 14 1
Days of grazing per year available from both temporary and permanent pastures used for dairy cattle at experiment stations in Louisiana

Forage values		*Months*												*Grazing days*	*% of total*
Quantity	*Quality*[a]	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*		
Surplus	Excellent			24				17				23	31	95	27
Adequate	Good		14		9	15								38	11
Adequate	Fair[b]	25	14	7	21		15	14	31					127	36
Deficient	Fair						15							15	4
Deficient	Poor					16				30	31			77	22
Total		25	28	31	30	31	30	31	31	30	31	23	31	352	100

Source Adapted from Cross 1963
[a] Based on daily evaluations of quantity and quality of grazing available using standard scoring system
[b] Level of quantity and quality beyond which forages from other sources would be required to provide the desired total feed energy per day from forage

ciently as possible into livestock products His feed budget would thus consist of an estimate of the number of animals that could be carried most effectively by the forages likely to be available within a given time

Table 14 1, based on experiences in southern Louisiana with supplying forages for a dairy herd, illustrates the value of a feed budget With a combination of crops, grazing could be made available throughout the year, but effective use was restricted to about 350 days by problems of extreme wetness Even so, the forage supplies were sufficient in quality and quantity to provide maintenance requirements for the cow plus 5 kg of milk per day for only 133 days (38% of the time), with 41 of these days between April and October (The horizontal broken line in the table shows where changes in quality and quantity of the forages required additional supplements for total nutrient needs) During most of the year supplementary forages, as hay or silage, became necessary to avoid serious seasonal fluctuations in performance Silage was made from both the surpluses of pasture in March and April and the crops planted on a small portion of the land especially for silage making

In planning the feed budget, it should be kept in mind that different species of livestock need different feeding plans Poultry do not make very efficient use of pastures They can utilize local feed resources well only if those feeds have a high energy content The planning for swine should be along the same lines as for poultry There must be sources of concentrates with good quality protein to make swine a suitable livestock enterprise Well fertilized pastures

may be used for sows and boars, but growing pigs need relatively high quality feed for efficient performance.

In a dairy enterprise, the young calf should be separated from its mother soon after birth, and from birth to 6 months of age it should have high quality feed with a reasonable good protein content. Calves can utilize high quality grass at 1 month of age, but they should weigh 130–160 kg, depending on breed, before they can make satisfactory growth on forage alone. And there must be abundant roughage of good quality for adequate animal growth (0.5 kg or more). In the late stages of pregnancy (7 months or later) heifers need more and better quality feed than previously. Non-lactating cows can be fed about the same as growing heifers except in the late stages of pregnancy, when they need a feeding regime similar to that for pregnant heifers. Lactating cows will generally require forages plus concentrates for efficient production levels.

In beef operations, calves can usually make satisfactory gains on milk alone from birth to weaning if the supply is adequate. They will also make some use of the available grazing. Heifers expected to be used as herd replacements need treatment similar to dairy heifers. Beef cows, on the other hand, can absorb fluctuations up to 20% in body weight without serious consequences, provided management is such that these animals are gaining during the late months of pregnancy and are well fed in the early weeks of lactation.

Steers may be handled in either of two ways: (1) kept in a continuous gaining state from weaning to time of sale or (2) allowed alternate periods of gains. For continuous growth, the animals should receive sufficient feed for gains of at least 0.6 kg per day in order to be profitable. If feeding is below this level, too great a proportion of the feed is used for maintenance purposes. It takes reasonably good quality forages to attain this level of gain. Alternatively, the animals may be kept on feeding slightly above maintenance level—at least 0.2 kg per day—from weaning until 1 year of age or later, then put on a feeding regime that will provide continuous gains of 0.6 kg or better per day. If the period of low gain or maintenance is continued too long, economic losses will be high because of the vast amount of feed required for maintenance purposes.

Lambs that are to be marketed at a young age must be kept in a continuous gaining state; whereas ewes, lambs, or wethers maintained for wool production can tolerate slower rates of growth. Nevertheless, seasonal body weight losses during the growing stages should not exceed 10–15%. Ewes may be treated very much like beef cows; that is, they may be permitted periods of losses in body weight provided they are gaining in the late prepartum and early postpartum

periods However, weight losses above 20% will materially affect wool production, as the fibers will become brittle and lifeless, probably because of a decline in the rate of sebaceous secretion brought about by the low nutritional level The flock kept for wool production can often be maintained on forages alone if their quantity and quality is fair to good, but for mutton production, the forages must be good to excellent in quality to produce satisfactory carcasses

The final feed budget, beyond providing for the anticipated requirements of the livestock, must have flexibility to meet unexpected fluctuations brought about by rainfall, and the operator must maintain constant vigilance to see that shifts of feed supplies are executed before serious losses of weight or milk yield result

MANAGEMENT OF GRAZING

Grazing management may be described as the art of arranging the optimum relationship between available forage and grazing animals In most livestock enterprises, this amounts to matching near constant animal numbers to a widely fluctuating forage supply Attempts to accomplish this through a too simple grazing system results either in excessive waste of forage during lush growth periods or in underfeeding during periods of reduced forage growth—neither of which is acceptable, especially if animals are being produced for sale

Range and Communal Grazing Lands

Experimental evidence indicates that some form of rotational grazing is usually preferable to continuous grazing Even on unfenced rangelands benefits have been realized from labor employed in moving the herd or flock to a new area before the forages are overly grazed But control of grazing is rare on unfenced range and communal grazing lands In remote areas the deterrents are the costs of inputs required in relation to utility and the lack of structural operation procedures For example, the Llanos region of the central portion of South America is remote from markets and sources of materials needed to improve the grasslands, e g fertilizer and wire for fencing, and there are no programs for regular destocking in this region Regular schedules are often unfeasible because the cattle are owned by family groups and no one person has the power of decision on when to sell Also tribal control of grazing lands frequently inhibits their best use Tribes, like the Bassari of Southern Iran have vested authority in their tribal

council for decisions on when to move camp and route of migration, but regulation of stocking remains a decision within the families except in extreme emergencies.

Although communal grazing lands are among the most neglected forage resources, traditional grazing practices will continue unless changes are induced from outside—principally through efforts to make marketing more attractive. The objective would be to establish a program that could lead to systematic destocking and in turn promote more efficient utilization of the forages available. This should in turn lead to acceptance of ideas for restoration of grasses and regulation of stocking rates.

Open range grazing could be improved greatly in several ways. Stocking rates could be reduced to $\frac{1}{2}$ or $\frac{1}{3}$ for two or more years to allow recovery of the grasses. However, this period must be followed by a balanced stocking rate otherwise the cycle will repeat. Shifting of stock about on the range will frequently pay dividends by preventing extreme overgrazing in some areas. This type of management is currently recommended in several countries.

Even though the costs of fencing, fertilizer and replanting are expensive, experience in southwestern U.S., Mexico, Costa Rica, Colombia and Australia have shown economic gains from intensification on small tracts of individual farms. The practices employed range from fencing off tracts to prevent grazing until the dry season to enclosing tracts needed to improve grasses. The economic benefits arise in several ways. Some livestockmen use the enclosed pastures principally during the time most of the females are expected to calve or lamb. This has permitted control of the herd or flock so more attention could be given at the time of parturition to reduce losses of both young and the mothers. Other stockmen have used the small areas to minimize weight losses of fattening animals during the dry season. This helps reduce time to reach market weight and thereby reduce the total feed energy required for these animals while they are on the farm.

Other Grasslands

As the level of forage production increases, management of the forage becomes more critical. Adjustments of the periodic imbalances of forage supply and animal requirements have been accomplished largely by two means: (1) integrated use of a succession of pasture crops having different seasonal growth patterns, as protrayed in Figure 14.1 and (2) conservation of excess forage to provide feed during

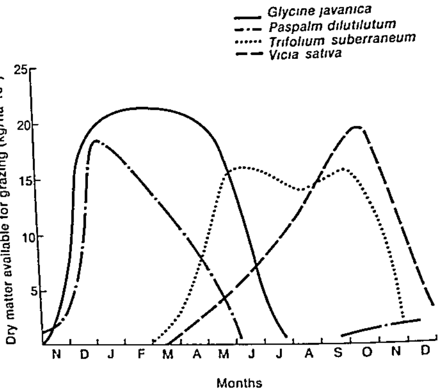

FIGURE 14 1
Feed-year system, recommended for pastures in subtropical Australia, capitalizing on the seasonal growth patterns of one grass *Paspalm dilutilutum* and three legumes (Adapted from Hudson *et al*, 1965)

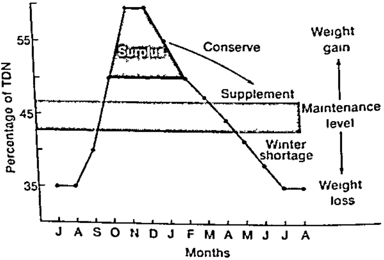

FIGURE 14 2
Diagrammatic portrayal of principles of fodder conservation (Adapted from Bonsma and Joubert, 1957)

periods of restricted forage availability and to insure best use of the total forage yields, as illustrated in Figure 14.2. All successful grazing systems utilize at least one of these adjustment mechanisms and many use both (see Chapter 6).

The standard concept of good pasture management includes rotational grazing, periodic clipping of weeds and mature growth, and harrowing to spread droppings. But there remain the questions: Which is the best system of rotation? How frequently should mowing be done and at what height for various pasture species? Should large numbers of animals be used to graze a small field quickly, or should small numbers be used over longer periods? Should fertilizer be applied, and if so, what kind, and how much? Should grass be used alone or in grass-legume mixtures? Under what circumstances should temporary pastures be employed? Recommendations for each question vary widely.

Rotational Grazing

For medium to high rainfall areas, the value of rotational grazing is debatable. In Australia, continuous grazing is now fully accepted as one of the effective systems under which pasture may be utilized. However, dairy operators have been slower in adopting continuous grazing although only 7% advantage has been demonstrated for rotational grazing (McMeekan and Walshe, 1963). In the Cauca Valley of Colombia, steers on continuous grazing of Pangola grass, fertilized with 150 kg nitrogen per hectare, gained nearly as rapidly over 333 day periods (0.53 to 0.60 kg/day) as those on a three plot rotational system (0.58 to 0.65 kg/day). In the Llanos region of Colombia, steers grazing continuously on unfertilized molasses grass did as well as those on rotational grazing using a similar area per animal (Ayala, 1969). Studies in Uganda comparing continuous grazing of East African Zebu steers to rotational grazing on six paddocks showed no major benefits for rotational grazing over a four-year period. Only when the quantity of available herbage was low did rotational grazing show advantages over continuous grazing. In contrast, tests in Puerto Rico using four species of grasses under heavy fertilization showed definite advantages in favor of rotational grazing. The gains of dairy heifers and the yields of lactating cows were higher from grazing small pastures for 3 to 5 days and allowing a 21-day rest period than from continuous grazing (Caro-Costas *et al.*, 1965). Apparently fertilization makes the difference. If medium to high levels of fertilizer are ap-

plied, animal gains per hectare are higher with alternate grazing But performance per animal may be similar for alternate and continuous grazing methods in the absence of fertilizer

Output per hectare is greatest where grazing is temporarily deferred until the plants have made a good growth of both tops and roots and have had time to store an appreciable amount of dry matter in stems and leaves

Strip or rotational grazing is certainly recommended for tall, summer or wet season crops, such as millets, sorghums, or sudan grass, since these stands may be badly trampled and wasted on a large pasture system

Pastures that are irrigated should be well fertilized, and rotational grazing or conservation of excess forage should be undertaken for maximum utilization of these inputs Irrigation and fertilization, by providing a more uniform level of grazable forage throughout the grazing season, help to balance the forage supply with the animal requirements Frequently, even rotational grazing will not provide adequate economic returns for high rates of fertilization and irrigation – especially in dry areas, like parts of Israel But where irrigation is needed for only a few months, as in the Cauca Valley of Colombia, grazing alone provides acceptable returns

Pasture Mowing

At present the practicality of mowing tropical pastures to control quality and quantity of forages is unsettled In the first place it is expensive It may do more harm than good for some grasses and may seriously damage trailing or climbing legumes, if they are present In Puerto Rico a mixture of tropical Kudzu and Napier grass provided 880 kg of animal gain per hectare when mowed once per year as compared to 650 kg when mowed at bimonthly intervals (Vicente-Chandler *et al*, 1964) But later experiments in Puerto Rico have shown no significant benefit from periodic clipping of stands of Guinea, Congo, Star, and Pangola grasses On the other hand, tests in Colombia showed that mowing at bimonthly intervals increased the carrying capacity per hectare for Pangola, Para, Guinea, and Puntero by 60% over no mowing (Table 14 2)

The Puerto Rico group recommended at least one clipping annually for Napier grass to keep the freshest growth at a convenient height for the animals Preferably this should be done by hand, as the lower cutting by a machine will retard the growth of the stand If cutting is done by machine, the stand should be fertilized after mow-

TABLE 14.2
The influence of mowing on the carrying capacity of four grasses in Colombia.

Grass	Carrying capacity (steers/hectare)	
	Unmowed	Mowed bimonthly
Pangola	1.56	2.50
Para	1.60	2.50
Guinea	1.45	2.00
Puntero	1.50	2.50

Source. Adapted from Alarcon y Lotero, 1968

ing and allowed 3 to 4 weeks recovery before grazing is resumed. It is wise to graze high yielding pasture plants short at regular intervals, if good yields of nutritious herbages are to be obtained, since the stems contribute a less acceptable portion of the grazing as the grass matures. Certain experiments have shown that better results can be obtained with heavy grazing than with mowing; plants that may suffer when cut short will not be harmed by grazing.

Overgrown pastures of Pangola, Star, Molasses grass, or Kudzu and Molasses grass mixtures do not require mowing since grazing animals trample them down while grazing on the newer growth. Even though much of the forage is wasted, the pasture recovers quickly if there is sufficient moisture. Nonetheless, on lands where mowing by machinery is possible, it may be desirable to cut back these pastures occasionally as an aid to weed control and to cut back overgrown spots where the forage has become less palatable.

No fixed rules can be made about removal of excess growth. Obviously, periodic removal of growth that seriously hampers the stand is desirable, but the need for frequent mowing on a well established stand suggests faulty management. Few general recommendations can be made on control of forage growth by grazing or cutting because the best system depends on the vegetative characteristics of the grasses. It is well known that after the emergence of the inflorescense stage, nutritive value is reduced, therefore, full inflorescense of a stand can be used as a guide on when to remove excess growth. It is also necessary to know the height to which a stand can be grazed or cut without deterring its recovery. This height is determined mainly by the localization of the nutritive reserves in the grasses. In most tropical grasses the reserves are stored mainly in the crown or in the first few centimeters of the stems above ground level. Para grass, for example, should not be grazed or cut less than 20

to 25 cm above ground level since this species does not form a crown and only stem reserves are available to regenerate growth, Guinea develops a crown and can be grazed to 15 cm, and Pangola and Star grasses can be grazed to 10 cm above the ground since they store reserves in the stolons Grasses like Napier store their reserves in the upper portion of the root system and in the crown, which means they can be harvested to 5 cm without a decline in their reserves Most tropical legumes should be managed in the same way as Para grass

Weed Control

Weeds are commonly a serious problem on poorly managed pastures, whereas they may constitute little or no problem under good management regimes The conventional methods of controlling weeds in pastures are through removal by hand or mowing, heavy stocking rates, varying the type of stock, mixing species during grazing, use of herbicides, and burning The best method will depend upon the local conditions, such as season, level of rainfall, and use of the pastures

In the humid tropics, shrubs and the regrowth of scrubby trees constitute the worst threats to grass stands If these are thorny species, control measures are desirable The best practice depends upon topography and availability of machinery In the lowlands, the most rapid means of removal is by tractor and rotary mower but on steep slopes removal by hand or the use of herbicides is more suitable Spraying of herbicides on large areas has not proven satisfactory except as a measure for clearing or retardation in preparation for seeding

In Australia and New Zealand it is common practice to use double or triple the normal stocking rate for short periods to graze off the excess growth and weeds which cattle will consume if forced to do so Another practice in these countries is stocking first with lactating cows to take off the choice forage and then with dry cows or steers to control growth of the forage and weeds

A few experiments have demonstrated that mixed grazing of goats with cattle or sheep is a good practice for the control of scrub brush but, except among th(Table 14 tribes, the grazing of mixed species has not been wide group recomm

Weedy pas grass to keep the f be reclaimed simply by applying fertilizer ne mals Preferably this and delaying grazing for a few months P by a machine will ret ier, Molasses grass and Kudzu Molasse one by machine, the stan y low growing grasses and weeds have

Stocking Rate

It becomes increasingly important to intensify grazing as fertilization of grazing lands is increased in order that the higher yields of forage produced will be utilized as fully as possible. On the other hand, intensification of grazing increases consumption of the less digestible portions of forage and, if pursued too far, can depress production per animal. Good management consists in compromising between maximum production per animal and maximum use of the forage in the pastures.

The productivity of a pasture is strongly influenced by the density of the stocking rate. There are no general guidelines for stocking because decisions must be based upon the characteristics of the pasture and the end result sought. In Australia and New Zealand, emphasis is currently being placed on returns per unit area. Freer (1958) demonstrated the advantages of this emphasis with the following statistics for lactating cows:

Year	*Cows/ha*	*Milk fat/cow, in kg*	*Milk fat/ha in kg*
1955-56	2.5	269	277
	4.0	249	405
1956-57	3.0	272	321
	5.0	242	489

Although the production per cow declined appreciably when stocking rate was increased, the return per hectare increased nearly 50%. Similar results have been demonstrated with beef cattle by Sprivulis (1967) for a low rainfall area (<70 cm/annum) during an 8-month grazing period:

Hectare/steer	0.40	0.61	0.77
Gain/head (kg)	189	189	212
Gain/ha (kg)	172	126	112

At the high stocking rate (0.40) the gain per head was 12% lower than at the lowest stocking (0.77) but gains per hectare were 54% higher.

Yield per unit of land has special significance when high investments have been made in that unit. But it may not always be the best gauge of stocking. In dairy production, it may be more economical when all factors are considered—namely, labor, facilities, number of herd replacements, and size of herd—to produce a given yield of milk by getting the highest return possible per cow. Likewise, a faster

turnover rate for steers, made possible by more rapid gains, may return higher profits In the rearing of female replacements, the stocking rate should be determined by a minimum rate of daily gain, irrespective of whether this rate gives the highest returns per unit of land

Stocking rate may have a marked effect on the botanical composition and the quality of the herbage consumed In general, the proportion of legumes in a pasture stand increases with increased stocking rate (Sprivulis, 1967) With more intensive grazing the grasses are suppressed and the legumes favored Such a change in makeup of a stand could be important where long dry periods prevail

Understocking is just as poor management as overgrazing Often the prime cause of low productivity and steady degeneration of a pasture is undergrazing, which permits the accumulation of rank inedible forage and the unchecked intrusion of weeds or less desirable species of grasses Experiments in Puerto Rico have shown that on pasture stands with 70% or more Pangola grass, steers or dairy heifers of over 200 kg grazed at the rate of 5 animals per hectare will gain 0 68–0 72 kg per day throughout the year, but if the stand becomes invaded by Para grass to the extent of 50% or more, gains with the same stocking rate will decline to 0 45–0 50 kg per head With high priced land and heavy fertilization, the difference in gains may mean the difference between profit and loss

Evaluations of pastures at several stocking rates with sheep or cattle are currently being made in numerous areas of the warm climates In these evaluations, emphasis is being placed on making forage the major feed source, through integrated programs of successive pasture crops to take advantage of the total growing season, along with supplements to prevent serious fluctuations in body weight when forage quality is low Much more information is needed in this area

Estimation of Forage Available and Carrying Capacity

There is no really satisfactory way of determining the amount of forage available for grazing, but fairly reliable estimates have been derived from agronomic measures, simulated grazing, and chemical analysis

(1) In one system, forage available is calculated as

$$\text{Dry matter per acre} = 85\,(H) - 190,$$

where H = sum of four measurements taken at the four corners of a piece of light plywood approximately 25 inches square dropped into a stand of grass (Alexander *et al.*, 1962). Assuming the four height measurements total 50 inches, $85 \times 125 - 190 = 4060$ lb dry matter per acre (4500 kg/ha). If the animals that will be grazing the stand require 11 kg of dry matter per day, the stand will theoretically supply their needs for 470 days; however, the calculated requirements of the animals should be increased 30% for waste—e.g., trampling. Hence, for a 28 day period the stand would be expected to carry 11 head per hectare or about 1.5 animals on a yearly basis.

(2) Forage available can also be estimated as:

Dry matter per unit of land = weight of fresh forage from quadrats − dry weight.

This system involves weighing of samples cut from measured areas randomly selected throughout the stand.

(3) Estimates from simulated grazing are accomplished by hand plucking of materials an animal might consume. The extent of the plucking on the individual plant is determined by the height the operator expects the animals to graze the stand. If a designated area is used, such as a 1 m^2 caged area, an estimate of the dry matter the animals may consume can be made as in (2). The simulated grazing is somewhat superior to the other methods for estimating what the animals are likely to consume.

For these estimates to be of practical value there must be corresponding estimates of the quality of the forage. As pointed out in Chapter 6, forage quality varies tremendously with age of the plant, season, and the portion of the plant being consumed.

From a practical standpoint, the best means of determining how well the animals are fed is to observe which portions of the plants the animals eat at a given time. When animals are turned onto a young, growing stand of grass, they first consume the growing points (Figure 14.3). This is the youngest and most tender portion of the plant. Next, they will graze the mature leaves and then, if the stocking rate is high enough that the animals are grazing faster than the growth rate, the upper stem and old leaves (those which have lost their bright green color). If the animals are left on a stand of Guinea grass until the plants are grazed down to 30 cm height, the average digestibility of the consumed material will range from 50–55%, which is marginal for animals expected to make good gains. In the early days of grazing from the stand the digestibility of the ingested forage equals or exceeds 65%. A stand of Guatemala grass like that in Figure 14.4 would

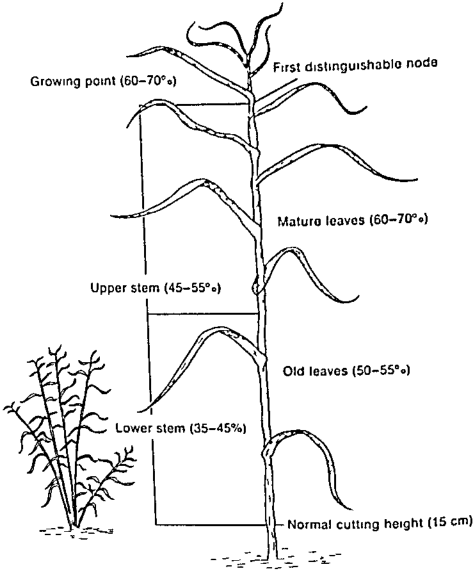

FIGURE 14 3
Illustration of the variation in digestive coefficients for portions of the stems and leaves of tropical grasses

correspond to the Guinea stand described But a stand that has reached the maturity of the Guinea stand depicted in Figure 14 5 would have little material that would be as much as 50% digestible

As can be seen from Figure 14 3, leaf-to-stem ratio of the plant influences the overall quality of the grazing For a grass like Guinea at 30 days of growth, the growing point constitutes about 5% of the total green weight, mature leaves 25%, old leaves 5%, upper stem 25%, and lower stem 40% With these proportions, the weighted average

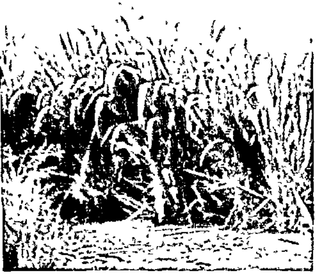

FIGURE 14.4
Young Guatemala grass (32 days) will provide good quality feed when green cut at this age.

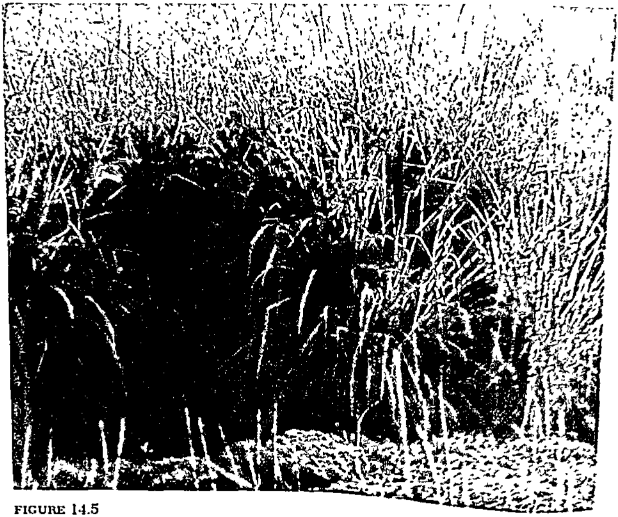

FIGURE 14.5
A stand of mature Guinea grass, which has low feeding value for either grazing or green chop.

digestibility for grazing to 30 cm height would be approximately 50% For a stand 60 days old or older, the weighted average digestibility would be 45% or less This level of digestibility would not constitute adequate quality grazing From this example, we can readily see that the high proportion of the low quality lower stem is the reason for less than desired consumption and growth rate from green chopped material as compared to grazing

Use of Fertilizer

Economic feasibility and water availability are the main factors determining the use of fertilizer, the quantity and composition of the fertilizer, and the schedule of application Since the best rate of application varies with the area, it is virtually impossible to make generalizations

In the humid, hill region of Puerto Rico, 2 5 tons per ha of 15–5–10 fertilizer, split into four applications, are recommended for grass stands This level of fertilization, along with some measures to control weeds, will provide 1100 kg of gain for steers or dairy heifers and serve as the feed supply for lactating cows producing 14–15 kg of milk per day for lactations of about 250 days (Caro-Costas *et al* , 1965) For the drier areas of the island (100 cm rainfall per annum), one application of fertilizer near the end of the rainy season is recommended, and about 1000 kg per hectare of complete fertilizer Tests in areas of Colombia with distinct wet and dry seasons, using Pangola grass, reveal that nitrogen fertilization markedly increased yields of dry matter (Table 14 3), but one application of 100 kg per hectare near the end of the wet season gave as high yields as applications of 50 kg per hectare at 6 week intervals

The most important factor affecting fertilizer requirements for grasses is the quantity of plant nutrients removed in the forage Since removal of nutrients in the forage is related to yields, the factors that affect yields also influence the needs for fertilizer If green cutting of grasses is employed, more than one application of fertilizer is necessary Generally, heavier applications of fertilizer are recommended if investments have been made in machinery for harvesting More fertilizer can be used profitably as value of land increases, where land is expensive, additional forage can be produced more economically by heavier fertilization than by planting larger areas Too, more fertilizer can be justified as the value of animal products increases It is more profitable to fertilize forages for the production of milk than of beef or wool Rather heavy nitrogen fertilization may be warranted

TABLE 14.3
Yield response (kg dry matter/ha) of Pangola grass to two levels of nitrogen applied in different seasons or to one level applied at 6 week intervals.

Nitrogen (kg/ha.)	Applications		Dry matter (kg/ha.)
	No.	Time	
0	0	–	590
50	8	6 week intervals	2340
50	1	Early in wet season	1220
50	1	End of wet season	1320
100	1	End of wet season	2320

Source. Adapted from Alarcon y Lotero, 1969.

when high protein concentrates are expensive and it is necessary to rely on forages as a source of protein.

As nitrogen levels and forage availability are increased, grazing management must be more skillful to avoid severe losses from excessive trampling or fouling accompanying high stocking rates and for best utilization of the higher protein content following heavy fertilization. As shown in Figure 6.3 the crude protein content of highly fertilized grasses declines rapidly, especially after 30 days of growth. For the southern U.S. it is recommended that when 225 kg of nitrogen or more are used per hectare the forage should be harvested. Experiments have shown that with this level of inputs, forages are more efficiently utilized as hay or silage than as grazing. The practical objective of fertilization is to achieve a level of production that assures economic return. Often this will require less nitrogen than is required for maximum yield.

Less fertilizer is needed for grazing than for cutting as only about half as much forage and hence much less nutrients are taken from the land by grazing. And less fertilizer is required if manure is returned to the land. About 80% of the nitrogen, phosphorus, and potassium consumed by cattle is returned in the urine and feces. If all the manure, together with uneaten forage, is returned to the field without loss, it is theoretically possible to reduce fertilization to about 20% of optimum rates. However, even under the best conditions, about half the nutrients in the excreta are lost by volatization and leaching. How much the tropical environment influences the rate of loss remains unknown.

Well established grass-legume pastures, e.g., Kudzu-Molasses grass, need much less fertilizer for high yields than grasses alone. A grass-legume mix ought to have around 100 kg of potassium per hec-

tare annually unless the soil is well supplied with this nutrient In addition, about 200 kg of phosphoric acid and on acid soils 2 to 3 tons of limestone per hectare are needed every 5 years. Nitrogen should be applied to mixtures only when high yields are required in an emergency or to favor grass if the proportion of legume in the mixture becomes too high

Grazing Management in Different Types of Operations

A constant supply of high quality forage is considered essential for lactating dairy cows, and pastures should be grazed only as long as they meet this requirement In beef and sheep enterprises, efforts to maintain constant forage-animal relationships are ordinarily less intense Periods of restricted feed supply are accepted as economical, particularly for a cow herd or ewe flock maintained to produce "feeders"

Beef producers in the N-S 30° latitudes are reluctant to provide stored forages for use during periods of low pasture availability But in the southern U S , producers have extended the grazing season by growing annual winter grazing crops, particularly cereal crops, ryegrass, and clovers These are planted mainly by sod seeding during the dormant period of perennial grasses Others have used delayed grazing of forage produced during the flush growth period or made the excess forage into baled hay that is left in the field until needed in the cooler season of the year The animals consume the hay and whatever grazing is available Short periods of slow animal growth are sometimes accepted as a more profitable system than the expense of stored forage The main emphasis is on minimizing weight losses during the season of poor feed supplies

Frequently, high fixed costs per cow in buildings, equipment, and labor necessitate that dairy operators obtain relatively high production per cow Thus differences among pastures in their ability to stimulate or maintain production per cow are of major concern Success in using perennial crops during the period of extreme high temperature or dry season has been quite variable In those areas where clovers or vetch can be maintained as a significant part of the forage mixture, the levels of milk obtained per cow have been as high as with nitrogen fertilized grasses Summer annuals, such as millets or sorghum sudan crosses, have been considerably more useful than highly fertilized perennial grasses in maintaining high milk yields in the southern U S But these annuals may prove less successful than

grasses in warmer climates. The millets and sorghums have serious disadvantages in that careful management is required to produce a continuous supply of vegetative forage. Furthermore, millet pastures have at times reduced the butterfat content of milk when used as the only roughage source. A special stimulating effect from limited grazing of such pastures, expressed as milk yield, gains, or breeding efficiency, has been reported, but the effect appears related to a considerably higher intake of digestible dry matter than to any specific plant component.

In Chile, attempts have been made to adapt dairy operations to a seasonal system of lactation similar to that normally followed in New Zealand. The intended calving period was July–August, thereby restricting lactation to the lush growing season in the high elevations and to the wet season in the lowlands. This system has proven satisfactory in the highlands on white clover and ryegrass pastures, but has not worked well in the lowlands due to the short duration of high quality material in the grass stands.

Grazing for Maximum Intake

Under high temperature conditions cattle and sheep restrict or cease their grazing during the hotter part of the day, thereby lowering their total intake. The influence of high temperature on grazing behavior appears to vary with type of animal. Payne (1966) concluded from a review of observations on grazing habits in tropical areas that under warm, humid conditions the direct stress of the climate will cause serious curtailment of grazing among European breeds of sheep or cattle but that indigenous types of these species are less affected. Most studies have shown that lactating cows tend to divide their grazing time about equally in the periods A.M. to P.M. and P.M. to A.M. milking times until the maximum daily temperature equals or exceeds 25°C. Seath and Miller (1946) found that when the maximum temperature reached 30°C, daytime grazing declined markedly and grazing during the hours of darkness increased to some extent.

The possibility of using the best pastures for nighttime grazing is attractive, but the benefits from high emphasis on night (night being defined as the hours of complete darkness) grazing are not clear. Few experiments in the tropics have shown significant advantages in performance for continuous grazing over morning civil twilight to evening civil twilight grazing. The reasons for this may be the preference of cattle or sheep for grazing most intensively in the early morning or late afternoon, irrespective of whether the climate is uncomfortable;

annoyance from insects, and the limited capability of the animal to choose herbage during the hours of darkness

Since most of the experimental evidence points toward early morning and late afternoon as the times of highest intake, it would be wise to gear management practices as much as possible to these periods both in beef and milking operations

Observations in Trinidad, Uganda, Australia, and the southern U S showed that grazing during the hours of darkness accounted for only 7–10% of the total grazing time More of the grazing took place from morning civil twilight until the sun reached about 30° above the horizon The other major period was the corresponding time in the afternoon The intervening periods accounted for less than 20% of total grazing time In the Trinidad experiments, there was a short period of grazing around midnight, but this accounted for only 1–2% of total daily grazing time These observations were made on good to high quality pastures Wilson's experiments in Trinidad (1957) lend support to the hypothesis He found that confining dairy cows for four hours during midday did not reduce total feed intake If the cattle were not confined, they ceased to graze and made use of any natural shade available—as little as standing with their heads in the shadows cast by fence posts

Figure 14 6 shows the expected grazing patterns for lactating cows on good pasture when the maximum daily temperature is 20°C or less and when the temperature exceeds 25°C The preferred grazing times at 25°C strongly suggest that maximum intakes can be expected by completing the milking operation before 6 A M The afternoon milking should likewise be early—2 to 4 P M —in order to get the cows back on pasture for two or more hours before complete darkness

The best schedule for a complete drylot operation would be somewhat different The Facultad de Agronomia at Maracay, Venezuela has developed a very practical schedule The A M milking begins at 7 A M As the cows leave the milking shed, they go to a shaded lot where green cut roughage is available The P M milking commences at 5 P M and from there the cows go into paddocks without shelter except over the feed bunks, where green cut forage is again available (Concentrate feeding takes place at milking time) With the milking done just before and following the heat stress period, the environmental influences are minimized Putting the animals outside early in the evening promotes rapid cooling, thereby restoring heat balance The cattle are moved from the shaded lot for the P M milking in small groups to reduce stress imposed by crowding

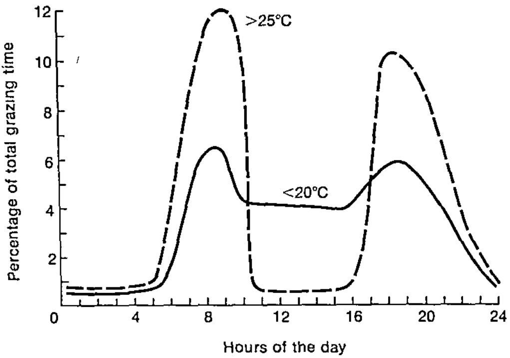

FIGURE 14.6
Contrasts in patterns of grazing for lactating dairy cows on good pasture when maximum daily temperature is 20°C or less and greater than 25°C.

Frequently cattle or sheep must be removed from the grazing and confined near the household to avoid high risks of predators, both human and animal. This occurs where quality of grazing is low and it is not feasible to provide supplementary feeding. Grazing could no doubt be increased by night grazing, but the risks must be weighed against the expected gains.

Essentially, the importance of the time allocated for animals to graze depends upon the quality and quantity of forage available, the demands of the animals, and the end result desired. Metabolic heat is also of concern. Cattle grazing on grass sufficient in quality for 0.45 kg of gain per day will show no measurable change in grazing behavior when maximum daily temperature exceeds 25°C. However, lactating cows will markedly reduce daytime grazing and some in their total grazing time if not given an opportunity to shift their grazing behavior. Considering all factors, the best management of hours of grazing depends upon the individual enterprise.

USE OF HAY, SILAGE, AND SOILAGE

Good levels of performance for beef and dairy cattle and sheep have been obtained with well coordinated pasture programs utilizing a suc-

cession of crops consisting of warm and cool season annuals However, the burden of coordination and management is reduced considerably by resorting to conserved forages as a means of utilizing excess production in periods of flush growth and supplementing or replacing fresh forage during periods of short supply

The wastefulness of grazing animals is continuously troublesome on high yielding, tall growing forages, especially in seasons of abundant growth (Figure 14 2) Consequently, all forages fed as green chop are rapidly gaining in popularity in subtropical areas (Green chop refers to cutting and chopping the plant into small pieces) Operators who employ a high degree of managerial ability may utilize a combined system of grazing, green chopping, and stored feeding, depending on season In this way they can take advantage of each at the most opportune time

Continuous use of green chopped forages is becoming widely practiced in dairy operations in the tropics (Figure 14 7) But this is not a panacea because it requires a skillful operator to provide uniform quality material Experiences in Puerto Rico, Venezuela, and Colombia have shown that if chopping of Napier, Guinea or Pangola grasses is practiced, the interval of cutting should not exceed 60 days, and preferably 30 to 45 days During this period the digestibility of the whole plant may range from 60 to 50% of the dry matter, but after 60 days the quality of the material is very poor (digestibility 45–26% and crude protein 7–9%) Many operators still do not realize the influence of stage of maturity on nutritive value, particularly of tropical grasses, and thus often exceed even 60 day cutting intervals (Figure 14 8) Unless the amount offered the animal is limited, 50% or more of the cut grass put before them will be refused When there is so much wastage, the cost per unit of utilizeable energy for the animals is quite high

The use of conserved feeds is attractive in terms of flexibility in supplying feed needs as it permits harvesting at optimum growth stages for best quality feed and storage assure near uniform quality in feeding It also avoids grazing waste, permits mechanization of feeding and eases the burdens of management. There is a growing trend among livestock operators near urban centers to place major emphasis on conserved forage or green cutting and little, if any, on grazed herbage The effect on animal performance of shifting from grazing to a stored forage system depends largely on the relative quantity afforded by each system and the level of concentrates being used

In principle, the problems of forage conservation are the same re

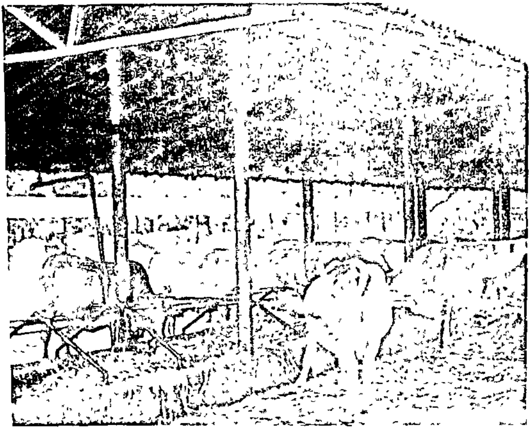

FIGURE 14.7
Maintaining a dairy herd in drylot with free choice feeding of fresh chopped grass sprayed with molasses has become a common practice in a number of lowland areas of the humid tropics.

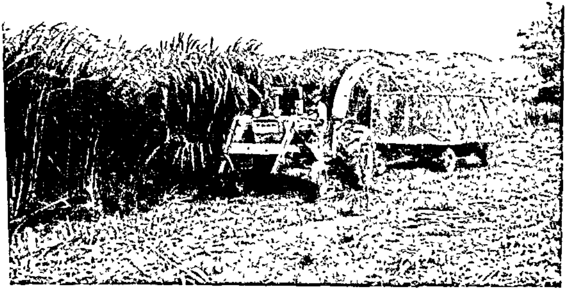

FIGURE 14.8
Green chopping of 90-day-old Napier grass to feed with molasses to lactating cows. The stem-to-leaf ratio is such that more than 50% is refused by the cows.

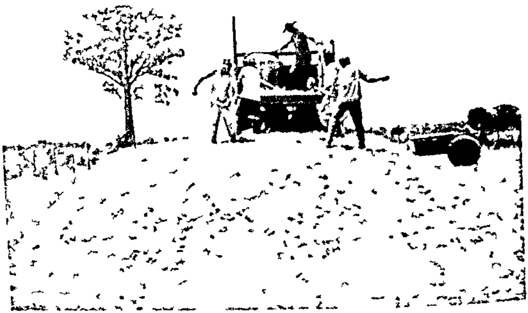

FIGURE 14 9
Preparing corn silage as a stack in the lowlands of northern Colombia The silage was covered with plastic sheeting weighted with dirt to reduce spoilage (Courtesy J C Johnson Tifton Georgia)

gardless of whether forage is a major or minor part of the total program Ensiled forage is playing an increasing role in both dairy and beef operations in certain areas Storage structures for silage vary greatly in design cost and efficiency Simple stacks (Figure 14 9) or bunkers (Figure 14 10) are effective when sealed with plastic sheeting or some other covering that insures protection from rain and oxygen If the covering material is thin a heavy layer of dirt straw or perhaps some other covering is required to minimize losses Permanent tower silos provide greater assurance of efficient preservation with a minimum of attention but at a considerably greater cost Pits may be dug into the ground but they have the drawbacks of problems with drainage and high labor costs for removal of the material It must be kept in mind that high ambient temperatures will damage silage quality even under excellent storage conditions

At the current stage of technology it is very doubtful if ensiling of many of the tall growing grasses native to the tropics is worth the expense because of the resulting low quality product When the grasses are freshly cut the moisture content is in the range of 75–85% which means there is a tremendous amount of water transported (A

FIGURE 14.10
Concrete bunker silos with all construction above ground level have proven satisfactory in the lowlands of northern Colombia.

moisture content of less than 70% is desirable for reduced weight, preservation efficiency, nutritional value, and animal acceptance). Tropical grasses tend to be much lower than temperate species in soluble carbohydrates, which are needed for adequate lactic acid formation to inhibit rotting. The resulting silage is both high in moisture and low in quality, because of poor fermentation. If silage is to become a feasible feed source in hot, humid areas, crops other than those generally available must be provided. Chemical preservatives, such as formic acid, have been tried in attempts to improve the quality of high moisture crops, but no process has become widely used.

Ensiling seems to enhance the feeding value of low quality feeds, such as cereal straws. Ensiled chopped oat straw with 0.9% formic acid solution and chopped straw with hot water fed to dairy heifers gave dry matter intakes of 0.94 and 0.72% of body weight, respectively, compared to 0.62% for chopped dry straw. These results suggest the possibility of improving intake of low quality roughages through the use of formic acid.

Conservation of forages as hay may be practiced where the possibility of rain damage is minimal, but because of the usual hazards of weather and kinds of materials it is usually less feasible than the use of the same crops as silage. Numerous experiments in the temperate zone have shown that when cows are fed good quality hay as the entire ration, they will produce 60–65% as much milk as when they are fed concentrates in addition to hay at the rate of 1:3. They will produce 70–75% as much milk on the hay alone as when fed concentrates in addition to the hay at the rate of 1:4 or even 1:6.

Except in semi-arid areas of the subtropics where alfalfa is pro-

duced under irrigation in the summer months there is little hay making in the N S 30° latitudes The techniques of hay making and silage are known in much of the region but serious drawbacks are operational and capital costs are high, especially for machinery and silos, there are not enough experienced people to operate the machinery, crops are unsuitable, and farm units are frequently too small to make ensiling crops economically feasible Where labor costs are relatively low, these problems could be reduced by means of cooperative handling and storage Small farmers in Japan seem to have an effective program underway for pooling surplus crops into a common storage facility Of course, farmers must first be convinced—particularly in the humid areas and in less intensive beef operations—that hay or silage can pay with existing livestock prices, management systems, and available manpower

Feeding programs based on stored forages or green cut material have additional advantages in disease and parasite control, reproductive efficiency, and reduction of mortality in young stock But under poor sanitation these advantages may be lost In spite of the projected benefits, it is readily evident that much more information is needed to determine the best system of storing the forages that tropical areas are presently capable of producing There is some preliminary evidence that the carbohydrate content of tropical grasses varies a great deal among plants If so, it may be possible to develop strains more suitable for silage

FEEDING OF CONCENTRATES

The merits of feeding concentrates in tropical areas—especially if the sources are imported, is a widely discussed issue There are essentially two schools of thought one, that livestock production in the tropics should be based solely on the use of forages for maximum efficiency, and the other, that concentrates are often needed to obtain the highest economic efficiency As is the case with other problems, no blanket recommendation will hold Those most optimistic about forage alone tend to ignore the fact that the cost per unit of feed energy in the form of concentrates may sometimes be lower than the cost from grass—as for example near an urban area where by products of food processing industries are available Besides, it has been well proven that the amount of TDN required per unit of product is somewhat less when concentrates make up part of the ration

Concentrates—those feed sources other than forages—are normally required for satisfactory swine and poultry operations, and

they are fed to cattle and sheep to (1) supplement inadequate forage supplies during extreme weather conditions, (2) enhance the total supply of feed energy to obtain near maximum or maximum performance per animal, and (3) extend a limited supply of roughage or expand the stocking rate of pastures where land acreage for the livestock enterprise is restricted. Dairy operators in the islands of the Caribbean and near urban centers elsewhere carry a higher stocking rate than can be supported by grazing or even green chopping. They rely on less than maximum intake of roughage and supply additional energy in the form of concentrates. The three groupings tend to overlap in application but the tendency is for feeding not to be at the level indicated in (2).

Insufficient dietary energy is often the result of an inadequate intake of dry matter; this may occur when forages contain less than 25% dry matter. And even a large intake of dry matter may have low energy value, or have sufficient total energy but lack one or more nutrients needed for the efficient utilization of energy. When this occurs, concentrate feeding may be utilized to balance diets, thereby increasing efficiency of utilization of all feeds available.

On a green weight basis, cattle weighing 200 kg or more will consume daily an amount no more than equivalent to 8% of their body weight when the forage is mature (digestibility of 40% or less). Daily intakes will increase up to 10 and 12% of body weight when the digestibility is 50 and 60%, respectively. If digestibility is 40% or less, the animal's energy supply will be no more or even less than required for body maintenance. The higher intakes and digestibility will provide energy needs for maintenance and milk yield or growth rate, but will not give the animal the maximum energy that it can utilize effectively.

The technical literature abounds with short-time grazing trials indicating that grazing alone will support average daily gains of 1.6 kg or higher for cattle and daily milk yields of 18 kg. But it has been demonstrated reasonably well that on a year-round basis about the best performance that can be expected from grazing alone is average daily gains of 0.5 to 0.7 kg and average daily milk yields of approximately 12–14 kg, with total yields of 2000–3000 kg in a lactation period lasting about 7 to 8 months. These levels of performance may be near the maximum genetic potential for some stocks, but for maximum performance from European-Zebu crosses or high grade European breeds, more energy is required. Since there is a ceiling on intake, determined by digestibility of forage, dry matter content, bulkiness of the grass, protein content, and type of forage (soft or hard leaf), a more

concentrated supply of energy is needed if maximum performance is to be attained

The gross efficiency of animal production—that is, the output per unit of total input—increases with increasing inputs above those needed for maintenance. And the energy cost of maintenance becomes an increasingly smaller proportion of the total energy input as the input is increased (Figure 14.11). At 2.0 to 2.5 times maintenance, which is near maximum on grazing, 50 to 60% of the energy intake is available for milk yield, in contrast to 80–83% when energy intake is 5 to 6 times maintenance. However, the increase in gross efficiency occurs at a diminishing rate with progressive multiples of maintenance because of the increased deposition of body fat.

Another way of looking at the relationship between energy requirements and milk yield is illustrated in Figure 14.12. If the forage has a TDN value of 50%, the usual intake for a 500 kg lactating cow will provide sufficient energy for maintenance and 10 to 20 kg of milk. If the forage is of excellent quality, (60% TDN), the level of production will be correspondingly higher. But when levels of 25 kg or more per day are sought, concentrates are required in order for the cow to have an adequate supply of energy. Hence, as yield per day rises, concentrates become of greater significance in the feeding program.

When body weight gain is the output unit, the same phenomenon occurs relative to maintenance needs, because fat (a high energy substance) constitutes a progressively higher proportion of the tissue gained as feed input increases. For this reason a fattening animal must consume 2.0 to 2.5 times its maintenance requirements per day in order to have an acceptable input output ratio.

It is not intended to infer concentrate feeding is suitable for all situations, certainly not. Providing ruminants with a high proportion of their total nutrients in the form of concentrate feeds is generally uneconomical. Nevertheless, there may be periods in the animal's life or particular economic situations in which at least certain concentrates may be a profitable source of nutrients. In the north central part of Venezuela, the cost per kg of TDN consumed as chopped Napier grass has been 1.3 to 2.0 times higher than the cost per kg of TDN in the form of concentrates. Whereas, in Puerto Rico the average cost per kg of TDN from grass is about ½ that of concentrates. It seems to pay to supply extra inputs of energy, especially for animals undergoing fattening for market and lactating cows with 50% or more European breeding, as long as the increased performance breaks even on the price of feed.

Occasionally, it may be wise or mandatory to use concentrates even when the cost exceeds returns. Examples would include cows or

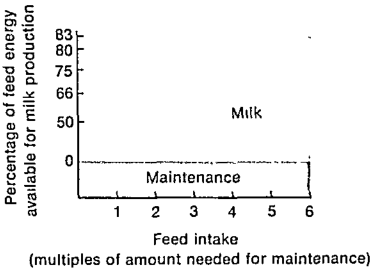

FIGURE 14.11
Illustration of the importance of level of feed intake with respect to the proportion of feed energy available for milk yield. (Drawing courtesy J. T. Reid, Cornell University).

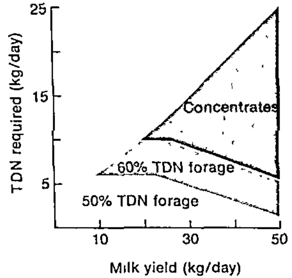

FIGURE 14.12
Illustration of the contribution of good quality forage to energy needs of 500 kg lactating cow with various levels of milk production. (Drawing courtesy J. T. Reid, Cornell University).

ewes that come into lactation 60 days or more before the end of the dry season. If they receive no supplement, milk yields may drop far below desired standards before the forages return to adequacy—even so low that the offspring are lost. Similarly, dairy cows that undergo serious restrictions in feeding for between the 60th and 140th days of lactation will not return to anywhere near normal production when the feed supplies are improved. Therefore, both the short and long range effects need to be taken into account.

Numerous experiments in tropical areas have shown little increase in milk yield following the supplementation of forage with

concentrates A number of these tests have used 2–3 kg of molasses per day as the supplement, without significant results No doubt the cows reduced their intake of forage, and thus failed to increase their total intake of energy, and actually decreased their protein intake If the animal is grazing forage of 5 to 7% digestible protein on a dry weight basis, it obtains a submarginal to marginal level of protein When the animal receives 1 5 to 2 0 kg of molasses in combination with grazing, its ration becomes seriously deficient in protein since molasses contains almost no protein

Another reason for the discouraging results with concentrates has been the low energy value (TDN) of the concentrate mixtures used If the supplement consists principally of by-products, the TDN value may be no more than 60 to 65%, which is not appreciably higher than that of good grazing In this case, the only significant advantage is some increase in total dry matter intake

The level of concentrate feeding recommended for lactating dairy cows varies with the level of milk yield and the quality of forage Frequently concentrates are offered at the rate of 1 kg to 2 or 3 kg of milk If the forage is sufficient in quality to furnish the needs for maintenance plus some for production, the 1 3 ratio may be most efficient, but if the forages are poor (less than 50% digestibility), the level of intake 8 to 10% of body weight, and the concentrate no more than 65% TDN, a ratio of 1 1 or not more than 1 1 5 may be required to supply the animal's energy needs

If concentrate feeding is contemplated it should be kept in mind that the ingredients should not be ground too finely or else molasses should be added to keep the ration from being dusty If the feed is dry and dusty, palatability will be lowered Dustiness of the ration definitely influences intake during the P M when respiration rate is elevated

Unquestionably, concentrates have a place in livestock feeding in the warm climates Their use necessarily depends upon the local situation

WATER SUPPLIES

As animals' demand for water is variable, no reliable estimates can be made of needs unless fairly accurate information is available on the type of animal, age, stage of productivity, type of feeding and the climatic environment (Winchester and Morris, 1956) All livestock require access to free water, some every few hours and some at less

frequent intervals. Livestock also obtain water from their feeds and from the metabolism of feeds. Swine and poultry in confined rearing must have water readily available, but cattle or sheep grazing lush pasture may require little in addition to that obtained from the feed. However, on dry feed or dry grass they need water in excess of 10% of their body weight each day.

Young animals consume more water in proportion to their body weight than mature, non-lactating animals of the same species.

At 20°C, 100 3-week old chicks, with a total weight of about 20 kg, will drink 5 kg of water per day, or 25% of their body weight, while 100 non-laying hens will drink only about 20 kg of water, or less than 10% of their body weight per day. Similarly, a 15 kg pig requires 2.5 kg water per day, or 17% of its body weight, while a 100 kg pig needs only about 10% of its weight per day (Winchester and Morris, 1956).

Lactating cows, sows, and ewes are obliged to have considerably more water than non-lactating animals of comparable age and weight. A pregnant sow ought to have 15 kg of free water per day, but one in lactation needs at least 40% more. A cow weighing 400 kg and producing 20 kg of milk per day may require over 40 kg of water.

Water consumption is, in general, directly related to temperature (Table 14.4).

At 18–20°C broilers need 0.7 kg of water per kg of feed consumed and almost 1.6 kg of water per kg of gain. If the temperature rises to 27°C about 30% more water is necessary. Swine and cattle need 60 to 80% more water at 25°C than at 10–15°C. As pointed out in Chapters 3 and 4, the rise in water consumption under high temperature conditions indicates the vital role water plays in thermal regulation. An adequate intake of free water is a means of maintaining performance efficiency in hot climates. If the water in unpalatable, contaminated, or high in mineral salts, consumption may be markedly reduced and with it the efficiency of feed conversion (Winn and Godfrey, 1967).

Lowering the temperature of the drinking water for livestock has proven effective in a number of cases. Cooling has practical limitations. Water temperature more than 10°C below air temperature tends to decrease water consumption and this much temperature differential may retard the rumen microflora. Although the gains of cattle on drylot feeding have been increased by refrigerative cooling of the water, the benefits have not been sufficient to make it economically feasible. If water is drawn from wells, there is little to be gained by added cooling except to keep the water as freshly drawn as possible. Shading a drinking trough is helpful. When the water is drawn from a

TABLE 14.4
Estimated daily water intake of various groups of cattle

Body weight (kg)	Liters per day by temperature[a]			
	10°C	15°C	20°C	30°C
DAIRY HEIFERS				
50	2.6	3.4	3.6	5.3
100	8.3	9.8	11.0	16.3
200	17.0	18.2	20.0	26.5
300	22.0	24.2	27.3	37.0
400	26.5	30.6	35.2	46.2
LACTATING DAIRY COWS[b]				
400	20.8	22.7	26.5	27.0
500	22.7	26.5	31.0	32.0
BEEF CATTLE ON MAINTENANCE RATIONS				
100	5.3	6.0	7.2	9.1
200	8.7	10.2	11.0	14.4
300	11.3	13.2	15.5	18.9
400	14.0	16.0	17.8	27.0
500	16.7	18.9	22.7	34.8
FATTENING CATTLE ON DRY FEED				
200	16.7	19.3	22.3	31.0
300	22.7	25.7	30.3	41.6
400	28.0	31.8	37.1	52.0
500	36.7	42.4	49.2	69.0

Source Adapted from Winchester and Morris, 1956.
[a] Estimates include both the free water consumed and water contained in the feed.
[b] Not including allowance for production

pond or collection area exposed to the sun, piping the water underground for a distance provides beneficial cooling Providing shade during the high temperature period will lower the need of water for fattening steers by 10 to 15% (Garrett *et al*, 1960)

Supplying adequate water for livestock in the humid tropics is not generally a problem, except when the water is contaminated with parasites Attention should be given to providing as clean a water supply as possible

In the dry and semi-arid areas, the high temperatures coupled with low water content of the feed supplies and scarcity of watering facilities make water supplies of prime importance In these areas

plans for adequate water supplies should be included in the overall schedule of feed production. A further handicap in semi-arid areas is that water supplies for animals are predominately brackish, such as the Pampas of Argentina, the northeast section of Brazil, most of Australía, a large part of northern Africa, and sizable sections of the U.S. Little is known about the effects of salinity on efficiency of animal performance. Most affected, of course, are the young of all species. Adult swine are more affected than cattle, and cattle more than sheep. Camels are most tolerant of salinity. The threshold level of injury for adults is generally about 10–15,000 ppm and lower for young cattle and sheep.

In general, pigs should have access to drinking water at least once each hour. Dairy farms ought to have provision for watering at least twice per day, especially for lactating cows. The greater the dependence on dry feed, the more the need to have water available continuously. It has been found that lactating cows on drylot with free access to drinking water produced 5% more milk than cows watered twice daily. For growing heifers and dry cows on good grazing, watering once per day is satisfactory. The same holds true for a beef herd. Sheep native to the drier areas seem to get along satisfactorily with watering once every two days, provided they are allowed to remain for several hours near the watering point. However, sheep deprived of drinking water up to 96 hours show a decrease in efficiency of feed utilization. Goats native to tropical areas seem to have a low water turnover rate—as much as 11% lower than that of sheep at high temperatures. Because of this they apparently need to consume less free water than sheep in order to survive.

The addition of salt to the ration will increase the water consumption of all species of livestock but no benefits have been ascribed to the salt.

If the watering schedule of any group is restricted to long intervals, there will be a reduction in dry matter intake. Hence water should be looked upon as an essential nutrient requiring as careful planning as any other phase of the livestock operation.

USE OF MINERAL SUPPLEMENTS

As indicated in Chapter 6, adequate supplies of certain minerals are essential for satisfactory performance of all types of livestock. Often the 15 essential minerals—sodium, potassium, magnesium, sulfur, chlorine, calcium, phosphorus, iron, copper, manganese, iodine, zinc,

cobalt, selenium, and molybdenum—are not sufficient in the animal's feed supplies The amount of supplement needed depends on numerous factors, among them the age of the animal, stage of lactation, types and quantity of feed, and soil conditions. Due to the limited information on the mineral content of tropical forages and soil deficiencies, it is difficult at this time to determine the minerals and amounts needed for a given area To insure that animals receive their minimum daily requirements, as set forth by the National Research Council (NRC 1966–71) This can usually be accomplished by supplementing the ration with a "complete mineral mixture" (Smith and Loosli, 1970) Such a mixture should include salt, a safe source of phosphorus, calcium, and all minor elements that are known to be deficient some place in the world, such as copper, zinc, iodine, cobalt and manganese, plus perhaps others (see Underwood, 1962) Mineral supplementation is not always feasible because of cost or system of animal management, but in some situations it is so necessary that all possible efforts should be made to supply them

Calcium and Phosphorus

In general, grazing animals receive adequate calcium, especially if they have some legumes, but inadequate phosphorus, particularly on phosphorus deficient soils (Chapman *et al* , 1964, Becker *et al* , 1953) On the other hand, animals fed limited amounts of poor quality roughages and heavy on cereal grains or by-products may have the opposite situation Nursing young or those hand fed milk or milk replacer diets seldom suffer from deficiencies of calcium or phosphorus since milk is an excellent source of both (Maynard and Loosli, 1969) Lactating dairy cows receiving good roughages and concentrates may not need calcium and phosphorus supplements, except in the early stages of lactation To avoid possible deficiencies, it is recommended that the concentrate contain 1% by weight of a calcium and phosphorus supplement To insure adequate growth and development it is also recommended that growing dairy heifers and dry cows in late stages of pregnancy on pasture have access to a calcium-phosphorus supplement free choice This may be accomplished by placing a mineral box in the grazing area A similar system of management is desirable for growing beef heifers and ewe lambs and for cows or ewes suckling young Supplementation of these minerals is not so important to "finishing" steers on good grazing, however, it has been demonstrated a number of times in Latin American countries that rate

of gain of steers can be markedly increased with phosphorus supplementation alone.

It is very difficult to set specific guidelines on calcium and phosphorus for swine since they may be fed a variety of feedstuffs. If the ration is entirely from plant sources, the addition of a source of limestone and a safe phosphorus-containing compound is recommended at the rate of 2% of the total ration (Smith and Loosli, 1970). When the ration contains feeds of animal origin—e.g., fish meal or whey—no additional calcium or phosphorus may be needed. If these feeds do not constitute at least 10% of the ration, 0.5% of an equal combination of limestone and phosphorus should be included.

It is important to make sure that the source of phosphorus does not contain toxic amounts of fluorine. If rock phosphate, a mined product, is to be used, it must have been treated to remove harmful amounts of fluorine. Fertilizer grade superphosphate, since it is not defluorinated, should never be fed. Mono- or di-calcium phosphates, defluorinated rock phosphate, curacao (mined phosphate with low fluorine content), and bone meal are all good suppliers of both calcium and phosphorus. (The user of bone meal should be sure that it has been properly processed to eliminate disease organisms.) If only calcium is needed, limestone and oyster-shell flour are both excellent sources.

Salt

Several experiments with grazing animals in tropical areas have demonstrated no significant benefits from supplementary salt feeding. The low returns from these tests may have been due to the types of animals involved or the animals may have obtained some supplementary salt from water supplies or the land area grazed. Non-lactating animals may need no supplementary salt or only limited amounts. Also suckling young do not need extra salt, since milk is rich in salt. The salt requirements of these groups are relatively low since they excrete small amounts. However, salt is extremely important for lactating animals. In fact inadequate salt may be a significant factor in the loss of young and poor mothering ability (Becker *et al.*, 1965). It appears wise, even in poor environments and where the cost of salt is high, to supplement the diets of lactating animals.

It is common practice to utilize salt as a means of supplying trace minerals. Such combinations are marketed as trace mineralized salt. A common formula (guaranteed analysis) on a percentage basis is salt

98.5, manganese 0.15, iron 0.078, cobalt 0.01, copper 0.015, iodine 0.007, and zinc 0.005. The usual sources of the trace minerals are cobalt carbonate, potassium iodide, manganous oxide, iron carbonate, copper carbonate and zinc carbonate, respectively. Many manufacturers add coloring, i.e., blue or red, to give their products distinctive markings. Mineralized salt may be prepared in block form to be used as lick or finely ground for compounding with concentrates.

Because trace mineralized salts are low in zinc for pigs where parakeratosis is a problem, it is necessary to modify the standard mixes.

Iodine

The iodine requirements are very low and easily met in most areas. However, in some areas there may be a deficiency. To insure an adequate supply the use of iodized salt, containing 0.007% iodine, is recommended.

Cobalt

The need for cobalt varies from one area to another. Most of Florida is seriously deficient in cobalt. For this reason, it is recommended that mineral mixes for cattle and sheep in Florida contain 0.03% cobalt (Chapman *et al.*, 1964). Other deficient areas have been identified throughout the N-S 30° latitudes. Unless it has been determined that there is no problem, it is recommended that a cobalt supplement be added at the rate of 2 grams of a cobalt rich material per ton of concentrate or 0.02 to 0.03% of the salt mixture. Ruminants can assimilate cobalt from cobalt sulfate, cobalt chloride, or cobalt carbonate, whereas pigs can use it only in the form of vitamin B12, a cobalt-containing compound.

Iron and Copper

Animals that subsist on milk only diets for prolonged periods, such as baby pigs, may become deficient in iron or copper, or both. Baby pigs kept on concrete flooring are likely to become deficient, whereas those on soil containing both minerals are not. Iron and copper can be added by painting the sow's udder daily with a satu-

rated solution of iron sulfate or even a parasite-free lump of soil. Or the needs may be supplied by one intramuscular injection of 150 mg of iron in the form of iron dextran at 3–4 days of age. This is enough iron, including some copper, to last through the suckling period (Smith and Loosli, 1970).

Most animals get adequate iron and copper from grazing; but supplements may be needed on certain soils. In Florida it is recommended that cattle grazing on sandy soils receive a mineral mix with 3% iron oxide (Chapman *et al.*, 1964) and 1% copper sulfate (Becker *et al.*, 1965). There may be many other areas of the subtropics and tropics where iron and copper are needed; but few of these have been identified, largely because these deficiencies are hard to distinguish from other mineral deficiencies or poor levels of nutrition.

Zinc

Laboratory analyses of tropical grasses have indicated that a number of them may be deficient in zinc for the needs of grazing animals. Although zinc deficiencies have rarely been identified, there are reports of suspected deficiencies. Zinc supplements may prove of value, but the requirements of cattle and sheep seem to be present in forages and water, and in mineral supplements as natural contaminants. The use of trace mineralized salt is good insurance against a possible deficiency at a negligible cost. Also there may be a need for zinc if there is an excess of calcium in the ration.

Parakeratosis in swine can be controlled by the use of extra zinc. The common recommendation is to supplement the total diet with 50 to 100 ppm of zinc. No more than 1000 ppm should be used, or problems of toxicity may arise.

Potassium, sulfur, manganese, and magnesium

Apparently most animals are able to obtain adequate amounts of potassium, sulfur, manganese, and magnesium in their feeds. However, grass tetany or grass staggers, which is associated with a shortage of magnesium in the diet, appears frequently. Occasionally extra magnesium, such as that contained in dolomitic limestone, has been reported as helpful. When molasses is used, an excess of magnesium sulfate often occurs, causing diarrhea and consequent inefficient use of the molasses. But since excess magnesium can be removed from the

body rather rapidly, fairly high levels of molasses can be fed without difficulty provided intake is not in large amounts over a short span of time

Mineral Mixtures

There are many types of mineral mixtures available, ranging from complete mineral mixtures to "premixes," which include one or more minerals Many of these may include urea or another protein supplement Others may contain purgatives, worm remedies, tonics, and "appetizers" General use of those in the latter grouping is not recommended due to costs They may contain items for which there has been no demonstrated need for livestock, and they may have less than the desired amount of the required minerals

The cost of mineral supplements must be kept as low as possible If the cost is high, either they will not be used at all or they will be used in such small amounts that in the end their use will be ineffective A simple mixture may include a source of calcium, phosphorus, salt, and iodine—e g , 50 kg of iodized or trace mineralized salt. This combination is universally recommended for lactating dairy cows If salt and phosphorus are reasonably available, the livestock producer can provide his animals with all the required minerals by simply adding a "premix"

Due to differences in feeding practices, the formulation for grazing beef cattle will vary due to soil type and content of forages In Florida, for example, cattle grazing on muck soils ought to have free-choice access to a mixture containing 86 1% salt, 12 9% red oxide of iron, 0 9% copper sulfate, and 0 17% cobalt sulfate, whereas those on sandy soils or where the water is brackish should receive a mixture of 43 0% salt, 43 1% steamed bone meal or equivalent, 12 9% red oxide of iron, 0 9% copper sulfate, and 0 1% cobalt sulfate (Becker *et al*, 1965) It is also recommended that these mixes include molasses and cottonseed meal to increase palatability A complete mineral mix recommended by Colombia's Ministry of Agriculture for grazing cattle consists of 10 parts salt, 5 parts bone meal, and 1 part trace minerals, including 1 95% copper sulfate, 7 47% iron sulfate, 1 24% oxide, 3 09% manganese sulfate, 0 20% cobalt sulfate, and 0 07% potassium oxide

In mid-continent areas, minerals may be very expensive because they are scarce The cost of salt in central Brazil is over five times higher than on the coast, for example Where costs of minerals are

high and market prices for livestock are low, the operator may have to forego the benefits of adequate minerals. Even so, he should recognize that some supplementation, such as salt for nursing cows or ewes, may be worth the investment.

As pointed out in Chapter 7, considerable interest has developed in the use of supplements that will furnish both protein and mineral elements. Protein meal-salt mixtures have been used successfully in the southern U.S., Peru, Kenya, Iran, India, and elsewhere. These pasture supplements, including mixtures with urea, have merit if properly used. The decision about which to use (a protein-mineral combination or a mineral mix alone) should be based on the available pasture forage, the relative cost of the two types, and the end result sought in animal performance.

REARING YOUNG STOCK

The rearing of stock from birth until the time when they can make satisfactory use of forages or coarser feedstuffs is a problem throughout the world, primarily because young stock require high quality feeds. Dairy operators in Puerto Rico and Venezuela sell most of their calves at one day of age due to the risks and the expensive feedstuffs needed to rear them.

Unless the operation is located where dried milk products are reasonable in cost, it appears best to feed the calf on whole milk for at least one month and then replace this with a ration consisting of lower quality feeds, such as wheat or rice bran, corn and copra, or cottonseed meal, along with some green cut grass of as high quality as possible. Calves of dairy breeds can make effective use of good to excellent pasture as a partial ration after one month of age, but most operators find this a more costly and less efficient use of land than pen feeding. Pen feeding also helps to hold down parasite infestation. Calves can be fed at lower levels of feed energy than recommended in the normal feeding standards provided there is ample energy and protein for skeletal development. The animals may make up for restricted feeding on lower quality feeds in later stages. It should be borne in mind, however, that if feeding, expecially of protein, is very low the animals will become permanently underdeveloped.

When the young are suckled but milk supplies are inadequate for the desired rate of growth, creep feeding of a supplement has proven satisfactory for beef calves, lambs, and pigs. Creep feeding of these species has become a standard management practice where maximum gains are desired in the shortest time. It is practical in areas

where concentrates are relatively cheap or preferential marketing conditions warrant use of rather costly feeds Temporary pastures of annuals can also be used for creep feeding should there be insufficient forage supply for both the dams and the young This may be especially useful in the development of herd replacements. Supplementary creep feeding with concentrates for replacement females is not desirable unless the grazing is very poor

As pointed out in Chapter 12, early weaning is being emphasized more and more because of such advantages as improved feed utilization, increased rate of gain, reduced parasitic infection levels, reduced labor, and increased reproductive efficiency through earlier rebreeding In Florida lambs from native ewes weaned at 70 days of age were 3 kg heavier at market date than lambs nursing until market date In other tests in Georgia (Baird and Sell, 1959) lambs weaned at 35 to 45 days of age and fed separately reached market weight as rapidly as lambs reared by suckling plus creep feeding The latter afforded advantages in cost of grazing per ewe and earlier rebreeding

Where grazing is the only source of feed, it is normally cheaper to feed calves and lambs through the mother up to at least a minimum body weight The length of time is dependent upon the breed and season of birth Calves should weigh at least 140–160 kg, depending on breed, or approximately 30% of mature body weight before being dependent on grazing alone With large breeds, such as Santa Gertrudis, a minimum of 200 kg is desired Lambs should suckle for about 90 days or up to 60 kg body weight for the larger breeds, but only about 30 kg for native breeds These minimums are equivalent to about 50% of mature body size

In grazing experiments conducted in Puerto Rico on highly fertilized grass pastures with heifers containing 50 to 75% Zebu breeding it was found that animals weighing less than 120 kg when put on grazing had an average daily gain of 0 19 kg for the first 2 to 3 months Those in the 150–160 kg range averaged 0 39 kg, and those weighing 225 kg or more averaged 0 71 kg Heifers starting at 110–120 kg required nearly 2 years to reach a slaughter weight of 385 kg, whereas those weighing at least 160 kg required only 400 days to attain the same weight. Even at an expanded stocking rate the smaller animals did not yield enough gain per unit of land to pay for the investment in improved grasses and fertilizer

When the milk production of the dam reaches a very low level, the young should be grazed on pastures separate from their mothers This has the advantages of increased gains, higher market grade, and, for lambs, less parasites (Sou Reg Bul , 1966)

During the post-weaning period (weaning to time of sale or first parturition) the feeding system is generally controlled either by the feedstuffs available or the endproduct desired. Cattle may reach a body weight of 400 kg by 12 to 18 months of age, depending on the breed and the level of feeding. If they remain on unfertilized natural grasslands, the average daily gain from birth onward will be about 0.2 kg per day; thus they will require about 56 months to reach 400 kg (Figure 1.2). At high levels of feeding about 2000 kg of TDN would be required for cattle to reach 400 kg body weight. Even if it took 2 years, only 2700 kg of TDN would be needed, as compared to over 4500 kg needed for a period of 50 months. Similar animals fed in the post-weaning period (over 8 months) for 0.7, 0.5, and 0.3 kg gain per day will require 20, 25, and 36 months, respectively, to attain 400 kg. A gain of 0.7 kg per day requires one-fourth of the feed energy, to produce 400 kg body weight, required by a gain of 0.2 kg per day. This implies that economics is a primary consideration in the rate of feeding. All roughage diets will normally require 23 to 30% more total energy than concentrate rations due to the slower growth rate (McDowell, 1966).

Lambs on full feed will reach 50 kg body weight in approximately 130–180 days after birth, depending on the breed. As with cattle, level of feeding will markedly influence the time required to reach slaughter weight.

Most commercial swine operators tend toward full feeding after weaning, their objective being to market the animals at about 6 months of age.

Even where feed supplies are not a limiting factor, young females are not fed at as high levels as animals being prepared for slaughter. However, there is increased interest, where land or feed is expensive in feeding dairy heifers for calving by 24 months of age. The common practice is to feed replacement females for a medium level of gain. For instance, gilts are placed on a limited diet after reaching 50 to 60 kg weight to prevent them from becoming overly fat before breeding at 8 to 10 months of age.

At present it seems to be economically wise to get both females and males into production at a reasonably young age. It is generally recommended that heifers be brought along so that they will calve by 3 years of age. Ewe lambs should lamb by 2½ years and gilts should farrow by 12 months; otherwise, disproportional amounts of feed energy will be consumed in the preproduction period. Well fed bulls of European breeds or crossbreds can be placed in service by not later than 15 months in contrast to 30–36 months and later when feeding

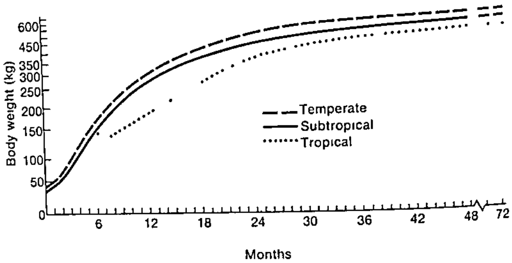

FIGURE 14 13
Growth rate of Holstein females from birth to maturity, plotted on semilogarithmic scale for New York (temperate) Louisiana (subtropical) and Puerto Rico (tropical)

is poor With reasonably good feeding, almost any bull can be ready for service by about 2 years of age

The influence of system of rearing on growth rate, age of first calving, milk yield, and return over feed cost can be illustrated by comparison of the practices followed in New York State, Louisiana, and Puerto Rico for rearing Holsteins (Figure 14 13 and Table 14 5) Holsteins grown in New York are larger than those in the other two areas at birth and remain larger until maturity The average calving age is slightly less than 28 months and the average weight at calving, 550 kg, the average first lactation yield is 5680 kg of milk, and approximately 3500 kg of TDN are used per animal from birth to calving The feeding consists of milk and dry milk replacer at early ages followed by concentrates plus roughage from 3 to 12 months of age From 1 year until approximately 1 month prior to calving the heifers receive roughage alone or 1–3 kg of concentrate per day, plus roughage

The growth rate of Holsteins in southern Louisiana parallels that for New York but at a slightly lower level The Louisiana Holsteins calve at around 30 months, at a weight of about 490 kg (Figure 14 13) Up to 6 months of age they are fed much the same diet as New York Holsteins, later they receive concentrates plus grazing and silage The estimated TDN consumed up to average first calving age is 3160 kg of TDN, and the average milk yield in first lactation is 4090 kg

In the better herds of the tropical areas the schedule of calf feeding is similar to that in Louisiana—milk replacer, followed by a calf

TABLE 14.5
Estimated TDN used for rearing Holsteins to several ages for first calving, expected first lactation milk yields, and estimated returns over feed costs for first lactation in Puerto Rico (tropical), Louisiana (subtropical) and New York (temperate).

Age of calving[a] (mo)	Tropical TDN (kg)	Tropical Milk (kg)	Tropical Return[b] ($US)	Subtropical TDN (kg)	Subtropical Milk (kg)	Subtropical Return ($US)	Temperate TDN (kg)	Temperate Milk (kg)	Temperate Return ($US)
24							2640	5230	345
26							2870	5360	355
28				2880	3955	260	3530	5680	375
30				3160	4090	270	3860	5790	380
32	2480	3000	200	3450	4218	280	4200	5900	390
34	2690	3130	207	3730	4346	290			
36	2900	3200	214	4020	4474	295			
38	3120	3330	220	4300	4602	300			
40	3330	3430	227						
42	3550	3540	234						

[a]Age span in which 82% or more of Holsteins calve for first lactation.
[b]Estimated returns over feed costs with base of $300 00 for 4540 kg lactation yields Feed costs and price of milk vary, but proportional returns are similar in all three areas

starter ration supplemented with fresh green cut grass. The growth rate for the first 6 months is not distinguishable from that of Louisiana. But after 6 or 7 months the heifers are turned on pastures with no concentrates, and for 1 to 2 months the calves make little or no gain. By this time they have been set back so much that they remain smaller until maturity (Figure 14.13). This is principally because they can not get enough nutrients from the tropical grasses to make up for the delayed growth period. Calving occurs at an average age of 36 months, and at an average weight of 425 kg. These heifers require more kg of TDN to reach calving age, even at a much lighter weight, and produce considerably less milk than either of the other groups. The economic return is not much better even when calving is delayed to heavier weights, as it is by some farmers in Puerto Rico since the increased milk yield for calving at 38 months does not cover the costs of additional feed.

In these comparisons the New York farmer is far ahead in economic returns. He has higher returns over feed costs in first lactation than the farmer in the tropics, and his cows are almost ready for a second lactation before the tropical dairy herd has the heifer in lactation. A series of grazing studies conducted in Puerto Rico (Vicente-Chandler *et al.*, 1964) have clearly shown that Holstein heifers can be

grown out on good quality, fertilized grass pastures after 7 months of age and can be expected to calve at 28–29 months of age, weighing 470 kg

SHELTERS

General guidelines on the feasability of providing shelters for livestock in warm climates are difficult to establish, principally because of the paucity of research data From the information currently available one can get evidence to support almost any position If animal comfort, measured by level of body temperature, is used there is general agreement that shades afford advantages in warm climates But if judgment is based on performance, the advantages are debatable The best guidance stems from applying research available regarding the use of shelters in relation to certain principles about the influence of climate on animals and the purpose the animals are to serve

Value of Shelters for Livestock in Hot Climates

Because some provision for shelter is common practice in dairy operations, researchers seem to have given more attention to beef cattle in their evaluations of shading A summary of a number of studies on the value of shade for beef cattle is given in Table 14 6 On drylot feeding, summer shades with aluminum roofs contributed to greater gains in southern California and Arizona than in Kansas (in the central U S) and Georgia, where it was not as hot as in California but much more humid Under grazing conditions slightly greater gains were reported for shaded than for nonshaded livestock, but the advantage was nonsignificant except for cows in Louisiana Additional advantages of shading in California were that the shade groups consumed more feed and required 25% less feed per unit of gain than non-shaded animals (Ittner *et al* , 1958) From present evidence it appears that significant improvement in efficiency of performance can be expected from the use of shades with drylot feeding in hot, dry areas but that little improvement will result from the use of shades with drylot feeding in warm, humid areas or with grazing in either hot, dry or hot, humid areas

Experiences in California and Arizona have indicated that the use of shades with cooling is a good practice for dairy operations In

TABLE 14.6
Value of shade for beef cattle.

Location	*Cattle*	*Shade*	*Average daily gain (kg)*
		DRYLOT	
California	Steers	None	.74
		Aluminum, with fan	1.04
Arizona	Steers	None	.66
		Aluminum roof	.87
Kansas	Steers	None	.90
		Aluminum roof	.96
Georgia	Steers	None	.98
		Painted metal roof	1.00
		GRAZING	
Mississippi	Steers	None	.47
		Trees	.68
Georgia	Steers	None	.59
		Metal roof	.62
Louisiana	Cows	None	−.02
		Painted metal roof	.38
		Trees	.52
	Calves	None	.54
		Metal roof	.81
		Trees	.79
Oklahoma	Cows	None	.65
		Metal roof	.83

Arizona lactating cows having access to shades with evaporative coolers had markedly higher breeding efficiency than cows having access to only conventional shades (Wiersma and Stott, 1965). In the same study milk production in the group maintained under the cooled shade was 1.8 kg more per day per cow than in the conventionally shaded group. This represented a difference of 6.5% between the total yields of the two groups.

Experiments conducted under more humid conditions prevailing during the summer months in Georgia and Louisiana have not shown that shades give any advantage. Lactating cows kept on drylot, with and without shade except for milking times, showed comparable

total feed intake, water consumption, and yields of milk, milk fat, and solids-not-fat. Similar results were obtained in southern Louisiana. In the Louisiana investigations, the level of fiber in the ration appeared to be more important in performance than shading (Guthrie *et al*., 1968). The addition of fans, sprinklers, or both in Georgia did not significantly improve the effectiveness of the shelters.

There are probably several reasons for the poor showing of shade in humid areas. Air turbulence is usually lower in humid climates than in dry climates, and it is further reduced when animals come into close proximity underneath the shade, thus the rate of convective cooling is reduced. The shade may offer some protection from the solar radiant heat, but this is apparently offset by the increased time required by shaded animals to restore their heat balance after sunset because of the slow rate of cooling. Another reason is that when animals are on relatively good pasture and do not need to cover as large areas as in dry climates, they tend to fill rapidly and spend most of the day under the shade. This leads to some reduction in the total daily feed intake of shaded as compared to unshaded animals.

Movable shades 3.7 × 4.9 × 1.8 meters high have proven sufficient to support satisfactory gains and feed conversion for swine on grass lots in Georgia. Although the addition of sprinklers brought about some increase in daily feed intake and rate of gain, the treatment did not decrease the amount of feed needed to produce a unit of gain. The conclusion was that additional costs and sanitation problems were created by sprinklers on unsurfaced lots. Under confinement rearing, the most economical means of reducing heat stress for swine would be through evaporative cooling. This may be achieved in one of three ways: (1) by providing an artificial wallow, where the pigs may be partially wet and presumably get out at intervals to dry, (2) by cooling the air with a fogger, which may also involve some wetting of the pigs, and (3) by spraying or sprinkling the animals periodically but allowing them to dry between wettings. Even these innovations have not proven worthwhile in Puerto Rico. Here, the open sided barn with partially slatted floors for feces and urine has proven best from the standpoint of animal health (Figure 14.14). The latter seems to offer certain advantages since wallows tend to become unsanitary and fogging cools a large quantity of air, only a small part of which contributes to evaporative heat losses from the animals. Tests in California (Morrison *et al*., 1968) showed that a sprinkling interval of 80 minutes was sufficient to keep efficiency of performance near the [illegible] nkling of swine is recommended for both dry and h[illegible]eriences in Calif[illegible] [illegible] shades with cooling

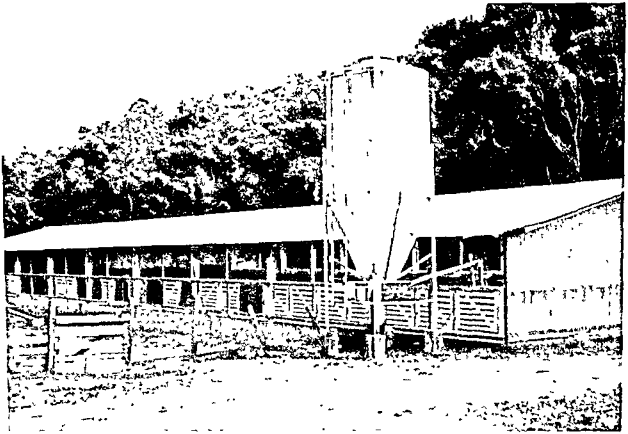

FIGURE 14.14
Housing for swine recommended in Puerto Rico.

Orientation of Shelters

If it seems desirable to construct shelters for protection against solar heating, the orientation of the shelter should be planned for best efficiency. A shade with its long axis running east to west will provide a cooler environment underneath than one with a north-south orientation (Kelly *et al.*, 1950). Ground temperatures will be lower under the east-west shade due to more shading during the day. For dairy and beef cattle, the north-south orientation is preferred because the short time of shading of the ground will allow it to dry more readily, thereby minimizing problems of sanitation. If the animals are free to move about the shade, they will shift position so as to use the shadow cast by the roof of the shade (Figure 14.15). According to Kelly *et al* (1957) the temperature of a clear sky on the west side of a shade while the sun is 0–60° above the horizon will range up to 20°C cooler than on the sunny side. The reverse situation occurs in the afternoon. When animals are underneath the shade there will be some radiation from the body to the cooler sky but Kelly *et al* found that animals standing in the shadow had a much greater opportunity for radiation to the cooler

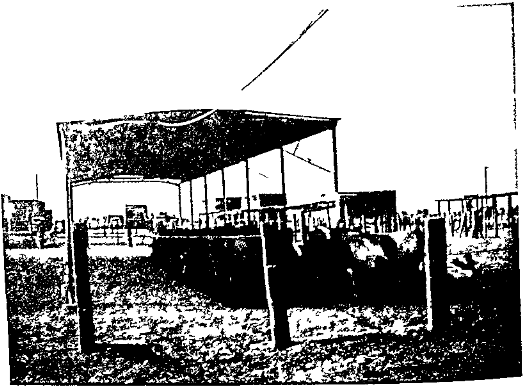

FIGURE 14 15
In a dry area, such as Arizona north south orientation of a shade creates a shadow which protects cattle from radiation and permits re radiation from the animal to the cool sky (Courtesy T E Bond USDA)

sky They, therefore, recommended north south orientation with allowance of free movement of animals as being the most satisfactory for cattle, especially in hot dry climates In hot, humid climates cloud cover will usually be such that the sky temperature on the side of the shade opposite the sun will be just slightly lower than for the sunny side This will limit the opportunities for using the sky to help promote heat loss, thus minimizing sanitation problems is the main reason for north south orientation in hot, humid climates

It appears that shades 2 to 3 meters in height are more suitable for warm, humid climates than the 4 to 5 meter height recommended for dry climates

Shade Covering

Over 50 materials have been tested for use as shades in California experiments (Bond *et al*, 1961) Their values ranged downward from hay or straw, which is best, through galvanized steel, lowered shades, plywood, and several types of plastics, to snow fencing, which is

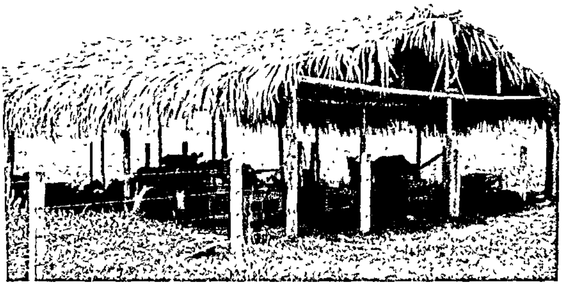

FIGURE 14.16
A thatched roof is adequate for protection against solar radiation but creates problems of sanitation in the humid tropics.

least effective. On a typical summer day differences in the radiant heat load under shades covered with straw and galvanized iron or plastics were on the order of 163 kcal/hr m^2 of animal surface. Hay or straw may be satisfactory for dry areas, but they are not very practical for humid areas because of the deterioration and sanitation problems caused by slowed drying (Figure 14.16). Painting galvanized steel with white paint reduces the surface temperature as much as 28°C. Where both water and drainage are available, wetting the roof surface aids in lowering the temperature; but this practice is not recommended for humid areas unless the water is collected to prevent run-off near the shelter.

Trees will generally provide acceptable shade, as illustrated in Figure 14.17. In many respects they are more suitable than constructed shades, especially for humid areas since trees allow better air circulation. The problem arises in relation to location of the trees and the grazing. Often trees are not located most convenient to the grazing area. Also trees are subject to severe damage from heavy concentrations of animals around them.

Sheets of polyethelene plastic are not very effective in reduction of radiation but this type of material can be placed over a frame to reduce wetting for newborn animals or to reduce drafts and chilling in large structures, such as calf rearing quarters. In southern Louisiana, the mortality and health problems of lambs, calves, and pigs were markedly reduced by use of plastic, either as a wind shield or as a protection from cold for young born in winter or early spring.

FIGURE 14 17
Trees with high tops and small leaf surface such as pines make excellent shading for cattle (Courtesy J C Johnson Tifton Georgia)

Space per Animal

A shaded area of 2 5 m² per animal appears satisfactory for beef cattle on drylot feeding Total pen space may go as low as 8 3 m² per animal without interfering with feed intake and rate of gain (Garrett *et al*, 1962) For lactating dairy cows a minimum of 5 0 m² of shade is recommended with a total pen space of at least 12 m² for drylot operations

Comparisons of rate of gain and feed conversion indicate that shade space of 1 9 m² is better for swine than either 0 9 or 0 5 m² Space per pig is more important for 50 to 100 kg animals than for smaller pigs (Bond *et al*, 1962)

At present, the cost of total air conditioning is considered too high in relation to returns to be warranted for any species of livestock, including poultry, except under unusual circumstances Where it would give the most benefit—warm, humid areas—the operating costs are extremely high because of the amount of water that must be removed from the air In hot, dry areas an evaporative or "desert" cooler is very practical and inexpensive to operate if there is adequate water available

For shelters to be profitable, they must improve the environmental conditions in a manner that can be measured in increased efficiency of performance In spite of the limited research on shelter needs in the tropics, a reasonably practical approach can be decided upon with the help of the Table 14 7 Shades may not be effective unless constructed of suitable materials and utilized properly—witness three unsatisfactory structures in Figures 14 18, 14 19, and 14 20

in contrast to two very practical structures, one for calves (Figure 14.21) and the other for lactating cows (Figure 14.22). Shelters seem to be a must in hot, dry areas, particularly for animals in confined areas and on high levels of feeding. In humid areas, the most suitable system is to provide access to shade during the warmer part of the day and to put animals in the open after sunset to promote loss of heat accumulated in the animal body. Animals treated in this fashion will usually maintain normal levels of feed intake and performance. Some practical facilities for milking shelters are illustrated in Figures 14.23, 14.24, and 14.25.

TABLE 14.7
Considerations for shade in warm climates.

Factor	*Environment*	
	Hot dry	*Hot humid*
Desirable for animal comfort	Yes	Yes
Most desirable type	Shed	Trees
Constructed shade		
Height (m)	3.7–4.3	2.4–3.7
Orientation	North-South	North-South
Flooring	Earth or concrete	Concrete
Roof shape	Sloping	"A" type with cap
Covering	Aluminum, straw, or any material with low emissivity	"Snow fence" or metal of light color
Shade with fans	No	?
Shade with fogger or sprinklers	Yes	?
Shade with desert cooler	Yes	No
Dairy cows		
Drylot	Yes	Yes
Grazing	Yes	?
Young stock, grazing	No	No
Steers, drylot	Yes	Yes
Beef cows		
Grazing	No	No
Drylot	No	No
Sheep		
Drylot	Yes	?
Grazing	No	No
Swine	Yes	Yes
Poultry	Yes	Yes

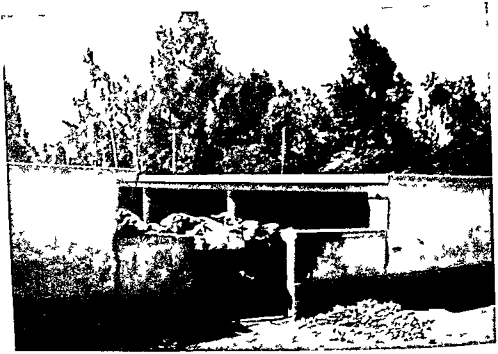

FIGURE 14 18
This housing is inappropriate for young stock, especially in a hot, dry region due to the high heat capacity of the concrete roof The high side walls reduce air circulation

FIGURE 14 19
Shades with concrete roofs are the least desirable particularly for a hot, dry area.

FIGURE 14.20
A shelter with a thick concrete roof and one side closed is even less satisfactory than an open shed with concrete roof (Figure 14.19).

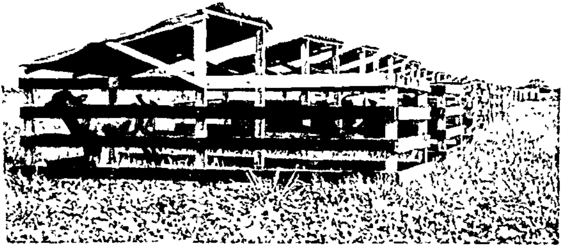

FIGURE 14.21
Rearing young calves in movable pens with partial roof has proven best for the humid tropics of Colombia.

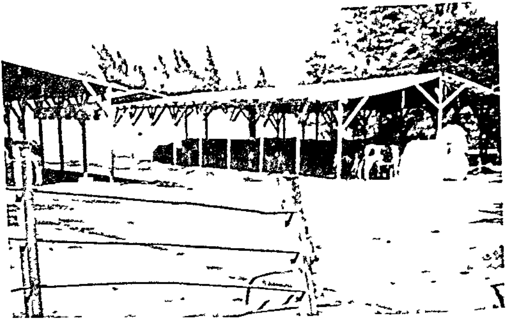

FIGURE 14 22
An open shed covered with straw has proven least expensive and most suitable for dairy stock in Egypt.

FIGURE 14 23
Inexpensive milking shed corral and milk house recommended for small farms in Puerto Rico (Courtesy R. Caro-Costas Puerto Rico Agric Exp Sta.)

FIGURE 14.24
In Madagascar milking stalls mounted on runners are popular for ease of movement from one grazing area to another. These stalls provide a means of restraint even for temperamental cattle and shade for both animal and man. (Courtesy W. Schulthess, FAO).

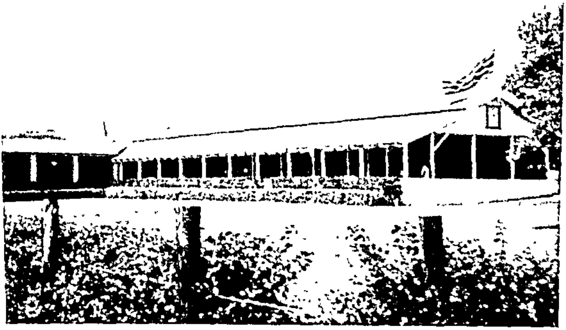

FIGURE 14.25
An open-sided barn for milking is recommended in Jamaica. (Courtesy L. E. McLaren).

CONFINED REARING

Confined rearing is used to describe operations where animals have been either completely or primarily removed from grazing Initially, the thought of confined rearing in the tropics is objectionable from several standpoints Nevertheless, it is already practiced to various extents in tropical areas for the same reasons that it is practiced in temperate areas expansion in size of operations, increased specialization, more efficient use of labor, rising cost of land near urban centers, and increased efficiency of crop production through the use of stored feed The outlook is for the continued spread of this practice in all countries, not only through expansion of existing operations but also as a means of making effective use of additional lands brought into agricultural production, particularly where expensive drainage is required Confined rearing and harvesting of forages will be necessary to support investments in these lands

Confinement often constitutes a major change in the animal's environment, which in many respects creates a need for a different set of management practices In warm climates it increases the importance of attention to animal health, such as the danger of rapid spread of communicable diseases, but at the same time provides an opportunity for utilizing protective measures Maintenance of a good degree of sanitation is mandatory This is especially true for minimizing health problems like foot rot Moreover, when adult cattle, sheep, or swine are kept continuously on a concrete surface, attention to such things as trimming of feet must become a part of the management system, although this may be unnecessary under grazing conditions

With sizable numbers of animals confined to a relatively small space, management practices and facilities such as buildings, equipment, and layout, take on added significance All too often the transition from continuous grazing to confinement takes place through gradual modification or addition to existing facilities When the transition is made in this way, the age of the animals, local building costs, labor availability, and problems of local climatic conditions are not usually given adequate consideration Inadequate planning in regard to these may lead to failure to attain the objective of shifting to confined rearing—namely reduction of unit production costs

Performance of confined animals can be affected favorably or adversely by the amount of space allocated to them, accessibility of feed and water, exposure to insects, presence of other animals, "peck order" social relationships, amount of shade provided, and other external conditions It has been found that cattle of 300 kg and larger

limited to 3 m^2 of slotted floor space required 20% more feed per unit of gain than those allowed 60% more space or cattle on dirt floors with 9 m^2 per animal (Maddex, 1967).

How to dispose of accumulated manure and urine in an efficient and sanitary manner is of major concern, especially in large operations near urban centers. In areas of high humidity, continuous dampness and ventilation for the facilities may be critical problems.

Although research on suitable systems of housing and handling for tropical areas is virtually nonexistent, the use of concrete surfaces for older animals and elevated pens for young animals, to increase dryness and control of parasites, appears reasonably satisfactory and widely accepted. However, in confined rearing of calves or other young, the mistake is often made of changing the animals from drylot and concentrate feeding to outdoor grazing in one day. Such an abrupt change negates much of the benefit of the confined rearing.

Probably the greatest disappointment in confinement systems in the tropics to date has been the lack of improved performance of older animals, such as lactating dairy cows. Oftentimes confinement and drylot feeding of green chopped forages have given no better or even poorer performance than when the cattle were grazing. This is because, on the average, the nutritive value of the harvested forage is considerably (5–20% lower in TDN) lower than the herbage selected from the same sward by animals grazing. Therefore, when the volume of herbage available allows a low stocking rate, conventional grazing results in higher performance than does the feeding of green chopped forage. The differences between green chopped and grazing may, of course, be offset by the additional energy expended by grazing animals. A cow, for example, may need 15 to 40% more feed on grazing to produce the same amount of milk as under confined feeding conditions.

These are not insurmountable problems, but they must be given attention if adequate returns are to be obtained on the capital investments in equipment and facilities for confined rearing.

CASTRATION OF MALES

Castration of males not designated for breeding appears to be an almost universally accepted practice with swine. But castration of rams and male calves, although standard procedure in some places such as the U.S., is practiced to varying degrees in other places or not at all. In many enterprises castration could serve a very useful purpose,

namely the initial step toward selective breeding This, and perhaps reduction in risks when handling appear to be the major benefits Experiments in Europe and the U S have shown that intact males will gain more rapidly than castrates under drylot feeding operations, but steers or wethers have higher carcass scores

There have been few experiments comparing the performance of intact males and castrates under continuous grazing conditions Preliminary evidence from Tanzania (Macfarlane, 1966) showed that up to 52 weeks of age there was no significant difference in the weight gains of castrate and intact Zebu males There was a trend in favor of the intact animals between 1 and 3 years of age, but the advantage was not maintained to slaughter at 4 years Dressing percentages were similar The weights of forequarters were nearly equal in the two groups, but the castrates were heavier in the hindquarters

Wound healing, if castration is done by surgery, can be a problem, especially in areas where screwworm is prevalent Emasculating is more commonly practiced as a bloodless procedure by using such equipment as a Burdizzo

Since intact males seem to have little advantage from the standpoint of growth and acceptability in most markets of the tropics, it appears that castration should be incorporated as a standard feature of management, primarily as an aid in genetic improvement.

There are certainly many additional factors to consider in determining the most efficient system of management Other aspects, such as the best season for breeding, are touched upon throughout the text.

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VI

SHEEP (AFRICA AND SOUTHERN ASIA) AND WATER BUFFALOES

15

RICHARD G. JONES

Sheep Production in the Semi-arid Areas of Africa and Southern Asia

There are approximately 1.06 billion sheep in the world (FAO, 1969), most of which are kept on the non-arable grazing lands of both the temperate and subtropical regions. Of these, more than 15% are found in Australia, nearly 40% of them above the 30° south latitude. Australia has mounted an extensive research program on behalf of her sheep industry, and this program has contributed much useful knowledge to the field. Its main focus has been directed toward increased wool production (Moule, 1968). South America has nearly 13% of the world's sheep, about 15% of them located in the region north of the 30° south latitude. As in Australia, the main objective of sheep rearing has been wool production, with meat a secondary purpose (Turner and Young, 1969). The largest numbers of sheep in the N-S 30° latitudes are in the region between 15 and 30° north latitudes, or the northern half of Africa and southern Asia. This region has more than 25% of the world's sheep population.

Even though sheep have been dealt with throughout the preceding discussions, those in the 15 to 30° north latitudes of Africa and southern Asia are singled out for some special attention for several reasons. In this region sheep are more important to a greater segment

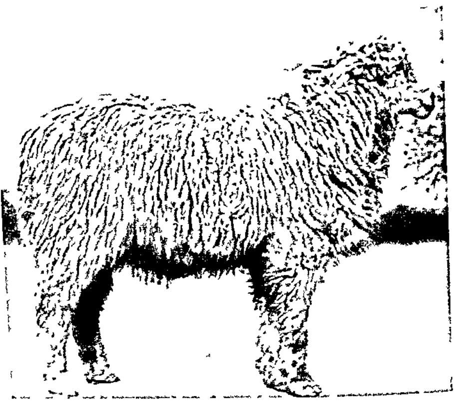

FIGURE 15 1
A ram of the Bikaneri breed, common to the villages in northwestern India. This breed is considered adapted to spare feeding and dry, hot regions Classed as a dual purpose breed, it produces milk and a coarse quality of wool. (Courtesy H C Pant)

of the agricultural population than anywhere else Secondly, the reasons for keeping sheep, in order of priority, are milk, meat, pelts, and wool, in contrast to the principal interest in wool or meat in other areas such as Australia and South America Thirdly, the cultural and political environments require somewhat different approaches to programs for improvement of production

Fourthly, the fluctuations in climate in this region can be disastrous even for sheep. The temperature may rise to 45°C on summer days and drop to −5°C on winter nights Sandstorms are frequent and wind velocity may reach 60 km/h Annual rainfall is not certain and successive years of drought may be followed by heavy rain, causing torrents The sheep in such an environment must be capable of withstanding extreme hardships Some breeds show reasonable tolerance to the climate but do not appear very productive when judged by the standards of other areas. The apparent poor performance of the local sheep has led to advocating diffusion by partial introduction of other breeds or complete replacement.

FIGURE 15.2
Ausimi or Osemi is one of the most popular breeds throughout northern Africa and southern Asia. It has been classed as a fat-tailed, coarse wool type and is used principally for meat and milk. The head is free of wool but covered with brown hair. The wool is white.

FIGURE 15.3
Somali or Blackheaded Somali is classed as a fat-rumped type. It has a white, hairy coated body, black head, and long slender legs. It is native to Kenya and Ethiopia but is found as far south as South West Africa. (Courtesy of T. Erasmus, University of Port Elizabeth, S. Africa).

Maintenance of sheep in this region is of two main types (1) a few animals owned by individual households among the sedentary population, and (2) flocks owned by families and herded as groups over migratory ranges There are a number of practices common to both But the types of sheep preferred by sedentary and migratory owners may be different. For example, the village sheep may be non fat tailed (Figure 15 1), while those maintained by the tribal groups are predominantly the fat tailed (Figure 15 2) or fat-rump types (Figure 15 3) The discussion will deal principally with migratory sheep raising

CURRENT PRODUCTION METHODS

Feeding

For both the village and migratory flocks, the main feed supplies come from grazing native grasslands adjacent to villages or migratory ranges plus cereal grain stubble, cereal grain straws, and perhaps some by products or forages The grasslands generally consist of annual grasses Most of these lands have been overgrazed for so long that many of the more palatable species of plants have disappeared Since the ranges are stocked beyond capacity, increased production from this source in the immediate future is impossible The fall and winter months are the most critical feed periods Death losses each year reach 20% or more of the total numbers, due almost entirely to lack of feed Often the migratory flock owners do not provide supplementary feeding beyond the use of straws Some tribal groups resort to housing their animals in caves during the winter months in order to reduce food needs Other groups may provide supplementary feeding during the winter, and a few may plant a crop of Berseem clover (*Trifolium alexandrium* L) for winter and early spring grazing, but such practices are not extensive, among either the nomadic groups or the sedentary villagers

Rearing of Young

In Iran, about two-thirds of the ewes lamb as 2 year olds and the rest as 3-year olds, depending upon the availability of feed and the season in which the ewe was born (Jones, 1964) If the ewes are well grown they may lamb first as early as 18 months (Ghoneim *et al* , 1959 Jones *et al* , 1968) However, in northwestern India, West Pakistan,

and Afghanistan the preferred age of first lambing for village ewes is 3 years due to higher milk yield and better viability of lambs (US AID, 1962).

In the whole region, most lambing takes place in the early spring —December through February in the lower latitudes, and January through March in the northern part of the region. Time of lambing is especially important for migratory flocks; each tribe determines the exact period for its flock. The percentage of twins is very low (about 2.2%) compared to temperate breeds. Whether the low twinning rate is attributable chiefly to genetic makeup or environmental effects has not been determined. But there is some indication that it may be largely due to nutritional levels, as similar ewes well flushed before breeding may have a twinning rate of 25% (Jones, 1964; Ampy and Rottensten, 1968). The average lambing percentage for mature ewes in most flocks is from 70 to 80% depending on feed supplies.

The birth weights for single ram lambs averages around 4.0 kg and 3.5 kg for ewe lambs. Some breeds, such as the Moghani of Iran, have flock averages of 4.2 kg for ewe lambs and 4.4 kg for rams. On good feeding most breeds will have birth weights exceeding 4.2 kg. Following birth, lambs are generally allowed to nurse at will for several days. Adoption of lambs is left largely to the ewes. However, the ewes are extremely good mothers, so few, if any, lambs are orphaned.

Under range conditions lamb mortality varies from 5–20% depending on the feeding conditions for the ewes and the time of lambing. Mortality is highest when lambing occurs after migration is under way. On government stations, mortality from birth to 2 months is 1–7%, which indicates that with good feeding the viability of the indigenous breeds is good.

Among the nomadic tribes, the lambs are never permitted to run with the ewes until the second or third month—the usual weaning time. The lambs are either kept in the village compound area or pastured separately when there is available feed close by the village or tribal headquarters (US AID, 1962). They are managed by young children. At night when the flocks are brought back the lambs are allowed to nurse and remain with their mothers overnight. Separation of the lambs from the ewes during the day is practiced to protect lambs from predators and permit the ewes to cover larger areas for feeding. This procedure is followed until the lambs are weaned. Normally, milking takes place at noon, after which the lambs are allowed to nurse for a short period before the groups are again separated. Some tribes follow this same practice in the evening. Milking for human consumption is begun after the first month of lactation. Because the lambs are only allowed one or two nursings per day and the remainder

of the time they are grazing, the weaning process is accomplished fairly early The average weaning weight is about 14 kg No favoritism is shown the newly weaned lambs, on the contrary, ewes are given the best feed so they will continue in lactation

Time of Breeding

Castration of ram lambs is usually delayed for a year or more, primarily so that development can be evaluated before animals are selected for breeding The age of breeding rams is generally from 1½ to 6 years Selection of rams is primarily on size and to some extent characteristics of the fat tail Little attention is given to wool yield and quality, body conformation beyond skeletal development, and size of tail or other characteristics Sometimes dark colors are deliberately selected because of the opinion that dark colored skin and wool reflect a stronger animal (Jones, 1964) The average ewe to ram ratio is about 12 ewes per ram, but among Karakul producers it is not uncommon to use one outstanding ram per 180 to 200 ewes This, of course, is with hand mating Rams are usually left continuously with the ewes, but this does not appear to greatly influence lambing as most of the breeds have a definite breeding season Also, since the rams do not receive any supplementary feeding, they show lowered libido and virtually no mating in the poor seasons

During the breeding season, the ewes are rather aggressive when in estrus This is especially true for Karakul, thus there is little difficulty in carrying out hand mating The average estrus length for several breeds is from 24 to 36 hours, with variations among ewes from 16 to 84 hours The ewes will receive the ram very readily any time during estrus The average number of services for conception is 1 2 to 1 4 (US AID, 1962) The occurrence of silent heat is relatively low (17–20%) in spite of the rigorous environmental conditions The interval from lambing to postpartum estrus may vary from 17 to 100 days with the average about 42 days Level of nutrition and number of offspring—twins or single—are significant factors in the time of estrus Ewes with twins have their first estrus 5–15 days later than ewes with singles (Sahni and Roy, 1967)

The breeding efficiency (proportion of ewes exposed to breeding that conceive) of indigenous breeds in this region appears to be as good as for temperate zone breeds Studies of migratory flocks in Iraq revealed an average of 17% infertile ewes per year But the average was as high as 30% in some years, depending on the proportion of young ewes and the time of previous lambing Among 2 year old

yearling ewes the annual infertility ranged from 20 to 40%. Poor fertility in this group was related to age and time of birth. Ewes born between October and December had good fertility, while those born in February were reluctant to breed as 2-year-olds. Infertility was high, too, in mature ewes that lambed out of season (February–March). Of course, the number of matings per ram and the ram to ewe ratio were additional factors in flock breeding efficiency.

Milk Production

Most of the native type ewes are reasonably good milkers, although there is tremendous variation within the breed groups. The Karakul, on the average, is the poorest milker. As in temperate zone breeds, the heritability for milk yield ranges from 0.20 to 0.27, with a repeatability of lactation yield of 0.40 (Soller *et al.*, 1966). In Iran the average lactation yields for Baluchi ewes was 50 kg in 80 days, with a range of 0 to 91 kg. Five-year-old ewes had the highest average yield. The average yield of a selected flock of this breed was 67 kg per lactation (Jones, 1964). Sandjabi (known elsewhere as Awassi) ewes in Iran averaged 24 kg exclusive of that given the lamb, which was estimated at 15 kg. This breed is considered one of the best milk breeds. Under good feeding conditions in Lebanon, the average yield was about 200 kg in 190 days, with yields as high as 300 kg per lactation (Choueiri, 1968). Typical Baluchi and Sandjabi rams are shown in Figures 15.4 and 15.5.

Where selection is practiced among ewes, emphasis is given to milk yield. However, selection among ewes is restricted due to environmental effects, particularly feeding conditions. Because of this, any genetic improvement comes largely from the ram side. Indirectly, consideration is given to milk yield of ewes through selection of ram lambs for breeding on size for age. Under such primitive conditions and wide seasonal fluctuations this is about all that can be expected (Soller *et al.*, 1966).

The average percent milk fat for the Baluchi, Sandjabi, and Moghani breeds is 6.21, 6.47, and 5.69, respectively. These averages indicate variations among breeds. However, some of the difference may be due to different sampling procedures—e.g., milking the ewe dry or leaving some for the lamb. A study of Baluchi ewes showed that the first 200 grams of milk drawn averaged 3.93% milk fat—approximately one-third of the total yield—the second 200 grams 5.07%, and the last drawn milk 7.20%. Invariably the ewe is hand milked first and the lambs nursed following milking, which means the lamb

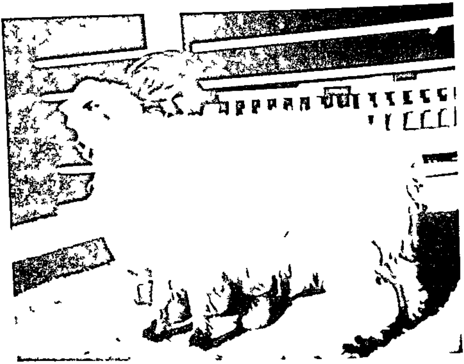

FIGURE 15 4
Two-year old Baluchi ram selected for stud on government farm in Iran The breed originated in West Pakistan and Afghanistan but it is also popular in Iran and Iraq It is classed as a coarse wool type but is a good milk breed and considered very hardy It has white wool and characteristic black nose and feet (Courtesy F Olvey U S AID)

FIGURE 15.5
Outstanding yearling Sandjabi ram that weighed 72 kg at 18 months of age This is one of the outstanding Kurdish breeds Its large size good milk production and desirable carpet wool make it popular among the nomadic herders (Courtesy R G Jones)

FIGURE 15.6
Typical method of milking in Iran. Children hold the head while the women rapidly milk with both hands by stroking the teats downward with thumb and forefinger. (Courtesy R. G. Jones).

receives the bulk of the fat produced. Because fat is of real importance in the production of cheese, it seems attention ought to be given to ways of changing this practice. The high fat content of the lamb's diet may also contribute to the incidence of enterotoxemia among lambs.

In both the migratory flocks and in the villages the women do the milking (Figure 15.6). The ewes are docile, and accordingly accept milking with a minimum of trouble. To what extent the presence of the lamb may influence milk let-down is unknown. It may be of some significance but evidently not nearly as important as for most cattle indigenous to the tropics.

Wool

Some of the finest carpet wools of the world are produced from the native fat-tailed sheep; especially in Iran and Iraq. Most of the best Karakul pelts come from the northern part of the region.

Shearing is generally done in the early summer months, when there is little, if any, possibility of further rain or cold nights. Since

the shears are usually very crude, shearing is slow, and varying amounts of fleece are left "Double cuts" are frequently made, which further lowers the quality of the fleece With shearing spread out over more than one month, some animals no doubt suffer from the heat before being shorn Tests in Iraq with twice-a-year shearing of yearling Awassi increased total wool production by 0 4 to 0 5 kg over single shearing, but there was no economic gain as the wool sold at a lower price per unit weight (Al-Aubaidi *et al* , 1968)

On a regional basis the average unwashed fleece weight is about one kilogram (US AID, 1962) Fleece weights may vary to some extent with age, feeding, sex, and breed Sampling from a large migratory flock of the Sandjabi breed in Iran gave fleece weights of 1 8, 1 8, 1 7, 1 7, and 1 8 kg for 3, 4, 5, 6, and 7-year-old ewes, respectively (Jones, 1964) In other studies, rams averaged 1 82 kg, while the mean fleece weight for ewes was 1 67 kg The average fleece weights for Sandjabi and Baluchi, which are given as 1 83 and 1 69 kg (Gadzhiev, 1968, Choueiri, 1968), indicate some variation among breeds Even so, yearly averages for flocks within breeds show as wide variation as those among breeds Lambs are first shorn at 16 months of age At this age their fleece weight is similar to the flock average Weight of fleece at first shearing is not given consideration in selecting rams

The customary procedures for handling the wool are poor When shearing is done during migration, the unwashed fleeces are tied in tight bundles The fleeces may be transported for as much as a month before being sold (Jones *et al* , 1968), deteriorating in quality in the meantime The only sorting at the time of sale is the separation of lambs wool Colors are mixed and length and grade variations are not observed

Susceptibility to Disease

Numerous diseases have been observed throughout the region Some observers attribute the high mortality rates to disease, but others contend that the losses arising from diseases per se are relatively low and that most losses result from poor nutrition The highest morbidity losses are from foot rot This also causes death becase it restricts grazing and there is no other feeding available The incidence of *Cl perfringens*—type B enterotoxemia—(lamb dysentery) in weaning aged lambs is often high It can be controlled by vaccination either just before or after weaning, but this it is seldom done, particularly among migratory flocks

White muscle (stiff lamb) disease is seasonally prevalent. Occurrence has varied from flock to flock and from year to year in the same flock. Morbidity has ranged from 5 to 20% and up to 50% in some flocks. Mortality has been estimated at 22%. The disorder has been observed most frequently between mid-April and mid-May and primarily in lambs from 15 to 45 days of age. Sex and breed do not seem to affect the incidence. Subcutaneous injections of sodium selenite (1%) has resulted in 94–99% recovery of affected lambs. Dosages of vitamin E given orally has brought about 94% recovery but a longer time was required (Ozcan, 1967).

A chronic infectious disease, paratuberculosis (Johne's disease) that causes thickening of the intestinal wall and recurrent diarrhea was formerly not considered present or unrecognized in the region, but it has been identified in several Ministry of Agriculture seedstock flocks of imported breeds in Iraq, Iran, and Jordan. Since rams from these flocks have been widely distributed, the disease is likely to create serious future problems in the region. Its presence may be quite widespread before recognition since parasitism and malnutrition are often mistaken for Johne's disease.

Tick borne diseases do not appear serious in this region. Also internal parasites are not generally a major problem among the migratory flocks although some losses are reported, especially when the sheep are housed under poor conditions (dark, dank caves or closed mud huts) during the winter.

Feed Requirements

The native sheep of the region are probably well adapted to survival on grasses low in nitrogen. It has been shown that Awassi sheep can retain urea at the renal level and are better able to utilize nitrogen recycled by the renal system than breeds studied in Britain. However, the availability of energy or other nutrients in the feed supplies may impose limitations on the extent of the utilization of recycled nitrogen.

In India it was found that adult rams could be maintained on 75% of the National Research Council's (NRC) recommended allowances of TDN and digestible crude protein. However, lambs from ewes fed at this level were subnormal in birth weight. Feeding at levels of 100–125% of the NRC standards gave the best reproductive performance and milk yields. From these findings, the consensus is that the energy requirements per unit of metabolic size ($w^{3/4}$) for good per-

formance is about the same for native sheep as for temperate breeds, but that native sheep can get along on considerably less total energy than is required for the larger temperate zone breeds

Marketing

The marketing of sheep in this region is a far more complex and intricate procedure than even the most remote producer faces in many other areas The vast problems the flock owner encounters in his normal marketing cycle have a tremendous effect upon production Transportation is a major factor as the absence of roads necessitates the trailing of animals long distances

As a general rule, most sheep sold for slaughter are priced on a carcass basis, while those sold from producer to feeder are sold by the head or "two by two" On some occasions animals may be weighed alive. When this occurs the price is usually fixed on a dressed basis and an arbitrary 50% yield is used to calculate the final price Prices paid in slaughterhouses are based on "hot" weights Generally, the pelts are sold separately

Selling periods for sheep and goats follow a definite pattern The lowest sheep receipts are in the winter and highest in early summer The number of females sold is low, about 10% of those 2 years or younger, 6% of the 3 to 4 year olds, and 10 to 15% of the 5-year-old and older ewes (Jones *et al*, 1968) This is due to the influence of migration, the high seasonal death losses experienced by the tribal groups, and the need to retain replacements

There is normally a "middleman" involved in the selling He is largely responsible for the stability or instability of the meat industry The middlemen travel to the tribal migration ranges and remote villages to procure animals for marketing in the large cities Their transactions are handled in cash and selling is by the head In the urban market the middleman may sell to a butcher or pay slaughtering fees and sell to shop keepers On some occasions a tribal representative may sell for the group to butchers at the slaughterhouses It is this group that seems to commit the most flagrant violations of ethical livestock marketing practices—witness the plight of producers who have sold their sheep to a butcher who, in turn, refuses to pay until he has retailed the meat The producer is not able to cope with dubious business dealings in the marketplace itself And given the political power of the butchers and particularly the middlemen, municipalities are reluctant to enforce the necessary rules and regulations to safeguard the marketplace for all

FUTURE PRODUCTION

There are some who favor improvement of cattle production at the expense of sheep production, believing that cattle will gradually replace sheep in this region. However, the values reported by Cook (1970) from studies under western range conditions in the U.S. suggest that pushing to replace sheep would be very unwise. Cook found that on a 12-month basis a ewe-lamb unit will convert the gross energy in range forages to salable body gain at least 20% more efficiently than a cow-calf unit. Assuming that sheep will continue to play a major role in the region, for economic as well as traditional reasons, the question becomes how to make sheep production more profitable for everyone involved.

Use of Local Breeds

In recent years attempts have been made to bring about changes in the local stocks, without very satisfactory results. For instance, the indiscriminate crossing of some of the Karakul types in the northern part of the region may well have brought about losses in some of the characteristics developed over countless centuries through both natural selection and deliberate planning of Karakul owners. The disruption of breed or strain continuity caused by these crossings can be attributed largely to modern economic pressures.

Over the past two decades governments have set up stations to produce "improved stocks" for distribution. These stocks have usually been crossbreds resulting from breeding a ram of an imported breed to local ewes (Figure 15.7). The breeds most widely used include the Merino of Australia and the Rambouillet and other breeds from the U.S. and Europe. Thus far, with perhaps the exception of the Turkish Merinos, programs have met with little success, because of poor communications with the tribes and lack of tolerance of the crossbreds to the rigorous environmental conditions. The poor breeding efficiency of purebred imported types or crossbred rams represents an example of the lack of adaptability to the local conditions.

Table 15.1 illustrates one experience in the use of an imported breed. The data summarize the comparative performances of Rambouillet and Moghani rams under drylot feeding in Iran. The rate of gain, feed per unit of gain, and final weight favored the Rambouillet, but the dressing percentage was 10% higher in the Moghani, and consequently the warm carcass weight was also higher. The higher dressing percentage was attributed mainly to differences in weight of head

FIGURE 15 7
A Rambouillet Moghani F_1 yearling crossbred ram The Rambouillet has been among the most popular breeds for crossing in Iran and Iraq The fat tail is much smaller in the cross than in the Maghani (Courtesy R. G Jones)

and pelt. The Moghani was low in weight of forequarter and loin but much higher in leg and fat of the tail The latter portion is preferred in local markets to the extent that the Rambouillet carcasses sold for less In the opinion of the sheep producers these marketing disadvantages far overshadowed the better feed efficiency of the Rambouillet

TABLE 15 1
Comparison of performance of Moghani and Rambouillet rams under feedlot conditions in Iran for 108 day feeding period Weights in kilograms

Factor	Rambouillet	Moghani
Initial weight	42 2	38 5
Final weight	59 3	50 2
Average daily gain	158	108
Feed/unit gain		
Roughage	5 79	6 65
Concentrate	3 68	4 36
Dressing percentage	40 5%	50 1%
Warm carcass weight	24 1	25 3
Pelt weight	6 1	4 3
Head weight	4.8	2 2
Weight of carcass cut from left side		
Forequarter	6 78	5 36
Loin	2.04	1.88
Leg and fat tail	3 67	5 77
Total	12 50	13 00

Another experience, in Egypt, showed that the native Barki lambs excelled pure Merino lambs in all traits related to body growth and viability. The Merino lambs excelled Barkis in fleece weight, but this potential advantage did not offset the losses in other traits in the view of would be users.

Crosses of local breeds with imported stocks have been fairly successful in flocks maintained at government stations, especially in terms of growth rate and wool characteristics, as illustrated in Table 15.2. In all characteristics the first cross of Merino and Barki (½ M) was superior to the other crosses and pure breeds. The Merino-Barki crosses also excelled crosses of local breeds (Barki-Awassi) in growth and fleece weight, but the Merino crosses were inferior to the crosses among local breeds in viability, breeding efficiency, and milk yield. Elsewhere, crossing among some of the indigenous breeds looks more promising than the experiences in Egypt. Crossing Polwarth rams with Rampur Bushier and Bikaneri ewes in India produced crossbreds with heavier fleeces, better growth rate, and higher milk yields (Kaushik and Singh, 1968) than either parent breed. Other tests with additional breeds made in Lebanon and Iraq have shown similar results. Thus, it appears that within the region, there are opportunities for improvement through selective breeding and crossing that have advantages over using breeds introduced from outside unless major emphasis is to be given to changes in fleece characteristics.

To bring about change, the nomadic shepherd must be shown the advantages of improved breeding. He is not normally willing to use

TABLE 15.2
Comparison of performance of crosses between imported (Hungarian Merino) and local (Barki) breeds and crosses among local breeds (Barki and Syrian Awassi) in Egypt. Weights in kilograms.

Breed group	*Birth weight*	*Weaning weight*	*Post-weaning daily gain*	*Greasy fleece weight*
Merino	3.3	16.0	.04	3.9
¾ Merino	3.5	16.7	.04	3.7
⅞ Merino	3.4	18.1	.06	3.5
½ Merino	3.6	20.1	.06	4.2
⅜ Merino	3.1	19.1	.06	4.1
¼ Merino	3.6	18.3	.06	3.6
Barki	3.4	18.3	.06	3.1
½ Awassi	3.5	18.6	.05	3.2
¾ Awassi	3.9	16.1	–	–
Awassi	3.8	18.9	.05	2.4

Source. Adapted from Fahmy et al., 1969

improved rams of even indigenous breeding that have been "artificially reared" Hence, government breeding programs based upon experiment station flocks have little acceptance with the average nomadic shepherd Nevertheless, it is possible to improve indigenous breeding in commercial flocks In Iran, three flocks (Baluchi, Moghani, and Sandjabi or Awassi) were established in 1959 The Moghani and Sandjabi were managed under nomadic conditions together with tribal flocks in that part of the country. Initially, these artificially established flocks were viewed with some distrust, but after three years, during which time breed selection and improvement were practiced, the demand for rams far exceeded those available In this instance, the tribal shepherds were shown breed stabilization and flock improvement under typical migratory conditions Although the same degree of improvement took place with the Baluchi flock, and in fact substantially greater improvement in wool production than with the former two breeds, the acceptance of the improved rams was much slower This was because the flock was maintained on the government farm where no doubt the conditions of rearing were better than the average Iranian producer could provide

Although the tribesmen are good animal husbandmen, they do not generally recognize the value of selective breeding The tribes occasionally exchange breeding stock with other tribal groups and the sedentary owners It appears, therefore, that the expenditures made by the governments for improved breeding through the use of imported breeds are somewhat premature Also, the imports or the crossbreds derived from imports have smaller fat deposits in their tails, a characteristic that is often discriminated against in marketing Furthermore, some of the tribesmen object to the changes in wool characteristics of crossbreds or imports because the finer wools are less suitable for making carpets and coarse, warm clothing

If government sponsored breed improvement programs place emphasis on changes in quality and quantity of wool, a marked rise in the prices received for such wool must take place for acceptance, unless milk yield and acceptance for meat increase correspondingly It is unlikely that crosses with breeds imported from the U S , Europe, or Australia will have significantly higher milk yields than a number of the indigenous breeds due to lack of selection especially for this trait

Throughout the region little attention has been directed to the maintenance of pure strains or breeds However, there are a few exceptions, such as the recent Ford Foundation effort to establish an Awassi foundation flock in Lebanon through the accumulation of outstanding animals of the breed from Lebanon, Iraq, Iran, and Syria

In addition, small government flocks of indigenous animals have been established in various countries to maintain the continuity of particular breed or strains. These flocks vary in size but they are small in number for breed improvement programs. Nevertheless, efforts of this kind should be encouraged as far as possible.

Before objective breeding programs can be undertaken, more data must be collected on the performance of indigenous types. Most of the information available gives only general descriptions of breeds or strains such as found in reports by Mason (1968), Jones (1964), and Gadzhiev (1968).

Feed and Water Supplies

The need for further study of types of feed, feed quality, and feed quality requirements for indigenous sheep is pressing. To date, most of the sheep of the region have been used primarily as scavengers. In many areas, full control of public grazing lands has not been realized. As a result, consistent overgrazing is the rule rather than the exception, and sheep numbers have often built up to the point of diminishing returns. Increased animal units grazing these depleted range lands result not in increased production, but in an actual decrease in productive units. This points up a factor frequently ignored by animal husbandmen—that is, the importance of enforced laws governing the use of public grazing lands. Especially in this region, animal production cannot be isolated from the social and legal patterns.

The major factor restricting the improvement in the contribution of migratory flocks is the scarcity of water. The average precipitation in the region is low; and the problem of providing forage supplies is further aggravated by frequent droughts. Since the tribes have little means of knowing about the grazing ahead of them as they migrate, they sometimes move into drought areas with disastrous results. Government sponsored programs could no doubt greatly improve the productivity of migrating flocks. For example, the central government, operating through its military organizations, could develop systems of communications (including radio broadcasts), aerial surveys, and weather forecasting that could serve to guide the tribes in their migrations. When drought areas are large, emergency feed and water supplies could be moved in to prevent severe losses. Watering ponds could also be developed along the main migration routes. If assistance in transport of animals from the grazing areas to market or feedlots were done on a systematic basis, it is estimated that the extraction rate per annum could be more than doubled. This would also re-

lease some of the pressures on the grazing lands, thereby indirectly contributing to restoration of grazing lands To those concerned with sheep production these steps seem plausible, but they may not receive much support from governments whose current policies are to eliminate the migrating flocks altogether for reasons of soil conservation and politics

It has been well demonstrated in several countries that finishing sheep from the range areas with drylot feeding is desirable from the standpoint of efficiency and total meat supplies This is economically feasible, and often permits better utilization of by-products produced in urban centers from the processing of crops like sugar beets and cotton (US AID, 1962) Also it has been shown in Iraq that the production of alfalfa under irrigation pays as the main supply of feed for fattening sheep When the alfalfa was mixed with straw, sheep gained from 0 12 to 0 17 kg per day In Egypt, Pakistan, and India the growing of Berseem clover during the winter months for fattening sheep has proved successful The deterrent to the widespread use of supplementary feeding for fattening sheep is the relationship between sheep producers and the "middlemen" who buy their sheep The "middlemen" pay low prices when they can for the fatter sheep for fear of infringement on their traditional control

Producer Incentive

Producer incentive—both type and amount—is a crucial factor in improving sheep production So far, relatively few cost return schedules (possible returns to producers with various innovations) have been developed Without this basic information, the chances of producers accepting practices to increase production are small

The political power inherent with livestock marketing is tremendous in this region The reluctance of both government employees and international livestock experts to involve themselves with the large sums that change hands each year—a reluctance stemming from fear of being implicated in any question of money mismanagement—retards the change of traditional systems Perhaps of even more importance is the lack of knowledge of most foreign advisors about livestock marketing in the region and the role that improved marketing can play in overall livestock development

Payment to a producer based upon a definite quality has not yet been initiated, and group or cooperative buying and selling has been largely ignored The purchase of animals on the basis of standardized weighing with accurate scales is practically nonexistent. Perhaps the

most typical of these problems is the lack of market information; the producers market their flocks without prior knowledge of market numbers or price. A serious complication in marketing is, of course, the migratory flocks since they must sell either before or at the end of the migration. The annual migration of various tribes means that within a country large numbers of animals are moving from generally poor range conditions to almost equally depleted areas. There are some exceptions, however.

In Iran, efforts have been made to establish the effect of animal migration on weight gains and losses. In three different areas 1500 animals were identified and weighed early in migration and again at the end. The weight lost during the summer migratory period each year equalled the total annual slaughter of Iran, as calculated by the Ministry of Agriculture (Jones, 1968). Without question the migration and resulting weight loss of Iranian animals is one of the major factors in animal management and economic return yet to be resolved.

Studies carried out at the Tehran market in Iran (Jones, 1968) and at the Baghdad market in Iraq (Jones *et al.*, 1968) indicate a wide seasonal variation in numbers and types of sheep offered for slaughter. During one year at the Baghdad market there were 24,156 sheep and 5300 goats slaughtered. Of these, 13.2% of all sheep and 14.4% of all goats slaughtered were 2 years and younger. The yearly average of female lambs was 7.3% of all sheep killed. As expected, a large part of the females killed were 5 years and older, 13.8% of all sheep slaughtered. This group made up 20 to 25% of the total sheep killed from April through September. The 3 to 4-year-old ewes made up 6.3% of the total kill.

A three year study at Baghdad revealed a recurring sheep and goat cycle. Sheep receipts were lowest from November through February and highest from April through June. Goat slaughter generally followed the reverse cycle. These two distinct slaughtering cycles were complementary in maintaining a constant supply of meat. When the sheep numbers declined meat prices rose, thereby attracting generally lower priced goats and old female sheep to the market. Obviously, better marketing procedures—through more uniform pricing—would provide impetus for a more fully developed livestock industry. The use of feedlots to increase weight per animal and to regulate the flow to markets would be helpful in stabilizing prices paid to producers.

As a producer incentive, as well as an effort to increase consumption of animal protein among the migratory people, the government of Lebanon has sponsored mobile cheese factories. Some units consist of two parts: mechanical milking equipment and a cheese proc-

essing laboratory The milking equipment is intended to improve sanitation and reduce labor The cheese processed in the laboratories is either marketed through governmental outlets or left with the tribes for their consumption Preliminary results indicate that use of the mobile units is accepted, however, further adjustments in feeding conditions are needed because of the restricted areas the units can reach These units afford other potential benefits as a means of recording that can be used in progeny testing, thereby affording an opportunity for breed improvement under migratory conditions (Choueiri, 1968)

The practical dependence on sheep in the region cannot be overemphasized The extensive range and steep mountain areas can only be profitably grazed by sheep and sometimes goats Thus, one of the most important aspects to be examined before the future role of sheep can be determined is social dependence upon the husbandry of sheep There is no question that the role of the sheep industry in the lives of the nomadic tribesmen is all important The milk constitutes the nomadic family's primary source of protein, and the fiber that is produced is used largely by the family Of even greater significance is the way of life of the Bedouin or the nomadic tribesman, whether in Africa or Asia, that utilizes range and grass resources that would not otherwise be used under the present governmental systems of land management. Unless sheep and those people associated with the sheep industry in the region "follow the grass," this resource will eventually be wasted and a way of life of millions of people, estimated at nearly 50% of the population of several countries, will be lost.

It is not the purpose of this chapter to expound the socioeconomic and family planning considerations that any government must evaluate before abolishing nomadic grazing It does appear, however, that in some instances legal restrictions imposed by governments to reduce the migrating or extensive society ignore the fact that some lands can best be utilized through migratory grazing of animals

There is one additional factor that must be considered if improvements are to be made—namely, human resources The needs for trained personnel will be high Currently, those concerned with sheep production in the countries of the region are pitifully few In Iraq, for example, one trained animal husbandry extension officer is assigned to the entire nation, where over 4 million people are engaged in some form of animal production

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16

H. C. PANT AND A. ROY

The Water Buffalo and Its Future

The world population of water buffaloes is about 119 million (FAO, 1969) with 80% of these in the N-S 30° region. India has the largest number, approximately 56% of those in the region. Buffaloes constitute nearly 23% of the total bovine population of India. Although the buffalo is considered a native to tropical or subtropical areas, several countries adjoining the N-S 30° region, such as Bulgaria, Romania, Yugoslavia, Greece, USSR, and Italy, have sizable numbers. According to FAO statistics numbers have declined in Europe over the last four decades, but they have increased more than 20% in the N-S 30° latitudes over the same period.

Since buffaloes make up about one-fifth the number of cattle in the N-S 30° area and in some countries serve as the major producer of milk, they warrant attention. The objective of this chapter is to provide a brief account of their origin, their general morphological characteristics in comparison to cattle, their current role in meat and milk production, and their possible future role in livestock production in the warm climates.

ORIGIN

The precise time of domestication of buffaloes is unknown In India they were domesticated by 2500 B C and in China about 1000 years later The migration of buffaloes about the world was not rapid In Egypt they were unknown during the Pharaonic times, they entered there sometime after the Arab conquest They arrived in Cambodia in about the fifteenth century The most extensive migration has taken place during the last few hundred years (Cockrill, 1966a)

The domestic buffalo is a member of the sub family "*Bovinae*" in the genus "*Bos*" The water buffalo of Asia (*Bubalus bubalis*) is distinct from the African wild buffalo (*Syncerus caffer*) both in number and pattern of the chromosomes The American bison (*Bison bison*) is not to be confused with the water buffalo

The *Bos bovinae* is found in the tropical and subtropical regions of Asia, the Philippines, Indonesia, and Trinidad, all countries of the Mediterranean basin, except France, and Melville island near the northern coast of Australia And some run wild in the northern territories of Australia

The present breeds are believed to have originated from the wild buffalo (*B arni*) of Assam in northeastern India and South China since features of one or other of the Indian breeds can be discerned in most other types The various breeds are represented by two main types the "river buffaloes" of drier lands, which are found mostly in India, and the variants of the "swamp buffalo," which are found largely in the rice growing lands east and south of Burma (MacGregor, 1941) India and Pakistan are the only countries having well defined breeds—over a dozen at present Even there, nondescript animals far outnumber the pure breeds The characteristics of these pure breeds have been described by many (Kaura, 1952, Randhava, 1962) The more prominent breeds are Murrah, Bhadawari, Jaffarabadi, Surti, Mehsana, Nagpuri, and Nili/Ravi

Murrah

The home tract of the Murrah (Figure 16 1) is mainly the Punjab and Delhi states of India This breed has a deep, massive frame with comparatively light neck and head, and short, tightly curved horns It has broad hips, short, massive limbs, a well developed udder, and a long tail reaching to the fetlock The skin is usually jet black but white markings on face, legs, and tail are not uncommon This is one of the largest breeds (Table 16 1) and among the best breeds for milk

FIGURE 16.1
The Murrah buffalo is the most popular breed in India and Pakistan. It is one of the largest breeds in body size and one of the best milk producers. (Courtesy H. C. Pant).

Bhadawari

The main habitats of the Bhadawari are districts of Uttar Pradesh and Madhya Pradesh states. This breed is medium sized (Table 16.1), and in the female the hindquarters are heavier and higher than the forequarters. It has relatively short legs, a long tail with black and white or pure white switch reaching to the hock, and copper colored skin with scanty hairs black at the roots. This breed has the highest milk fat percentage (13%). And the males are good for draft.

Jaffarabadi

The tract of this breed is Gujrat State. The Jaffarabadi has a long body (Table 16.1), usually black in color; a prominent forehead; and heavy horns, which droop on each side of the neck and then turn up at points, but not so tightly curved as the horns of the Murrah breed. The females have well developed udders, and they are good milkers. Their skin is usually black. The males are used for heavy draft.

TABLE 16 1
Average body weight and skeletal dimensions for adult males and females of several buffalo breeds

Breed	*Body weight (kg)*	*Height at withers (cm)*	*Length from point shoulder to pinbone (cm)*	*Heart girth (cm)*
Murrah				
Male	567	142	150	221
Female	431	132	147	217
Bhadawari				
Male	476	132	140	188
Female	385	122	137	180
Jaffarabadi				
Male	590	142	168	191
Female	454	140	160	188
Surti				
Male	500	131	142	186
Female	408	125	137	178
Mehsana				
Male	567	142	178	214
Female	431	132	155	208
Nagpuri				
Male	522	142	173	211
Female	408	132	142	206
Nili/Ravi				
Male	567	137	157	226
Female	454	135	147	226
Egyptian (Beheri)				
Female	588	145	169	217

Source Data from Kaura, 1952 Randhava, 1962 and Whyte and Mathur 1966

Surti

The Surti is found in Gujrat and Maharashtra states This breed has a medium-sized body with straight back and head long and rounded between the horns The eyes are prominent and tend to bulge, the horns are flat, sickle shaped, and of medium length, and the tail is fairly long, ending in a white tuft. Body color may be either black or brown Good specimens have two white collars—one round the jaw from ear to ear and the other at the brisket. The breed is considered a medium level milk producer

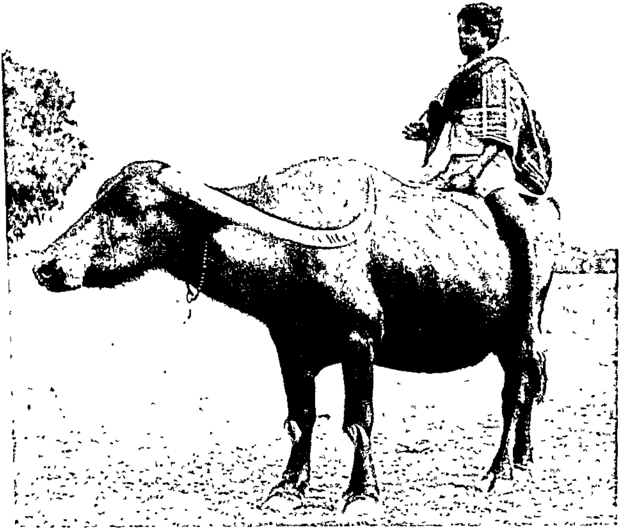

FIGURE 16.2
Nagpuri female buffalo native to central and southern India. Its long sweeping horns are its most distinctive feature. (Courtesy H. C. Pant).

Mehsana

The habitat of the Mehsana is Gujrat state. This breed is classed as an intermediate type between Surti and Murrah breeds. It has a longer body than the Murrah (Table 16.1) and lighter bone structure. The horns are longer than in the Murrah breed and less tightly curled at the ends. The skin color is black or fawn grey with some white markings on the face, legs, or tail tip. This breed excels in early maturity, persistence in milk production, and regularity in breeding.

Nagpuri

The Nagpuri is found in central and southern India. It is generally taller than northern breeds. Its most distinctive feature is the long flat and curved horns bending backward by the side of the neck almost to the shoulders (Figure 16.2). Body color is usually black with occasional white patches on the face, legs, and tail tip.

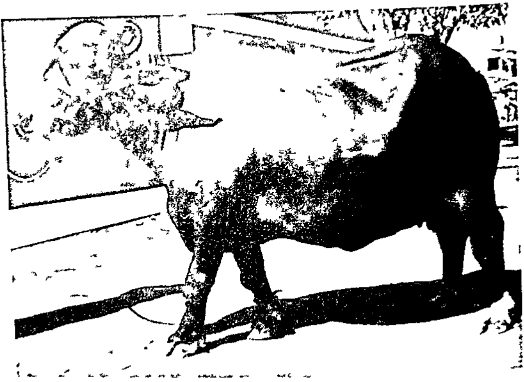

FIGURE 16 3
The Nili is the most important breed of buffalo for dairying in Pakistan White on the forehead and feet distinguish it from the Murrah breed (Courtesy H C Pant)

Nili/Ravi

Nili and Ravi buffaloes, which are found in the Sutlej and Ravi river valleys, were for a long time treated as two different breeds, but now they are considered as one This is one of the best Indian breeds, second only to the Murrah The body is medium sized (Table 16 1) The horns are small and lightly coiled, and the neck is long, thin, and fine The face and forehead characteristics distinguish it from the Murrah Its color is usually black with white markings on forehead, face, muzzle, and legs A white switch and wall eyes are also common (Figure 16 3)

In Pakistan the most common buffalo breeds are Nili/Ravi and Murrah The Nili breed is as important in the dairy herds of Pakistan as the Murrah is in India In other countries no recognized breeds exist. There are two main types of buffalo in the UAR, the Beheri in the north and the Seidi in the south (Alim, 1967) It is not known if

these classifications have any genetic basis as the "Egyptian buffalo" has no really distinguishing features, although it is slightly above average in size (Table 16.1).

Other Types

The swamp buffalo of southeast Asia has several variants, ranging from the massive Thai buffalo (700 kg or more) to the small carabao of the Philippines, which averages about 400 kg in body weight (Cockrill, 1967). The buffalo of Ceylon is considerably smaller and has more hair than the swamp buffaloes in other southern Asian countries. It has an average body weight of 250 to 300 kg, and in all other physiological and anatomical aspects it is identical to the swamp buffalo. The swamp buffalo is an excellent draft animal in the paddy growing tracts of southeast Asia.

Buffaloes in Brazil were imported mainly from India, the Antilles, Italy, and Africa. In Brazil, the strains of buffalo are named according to their color: the Marajó of the Amazon, a yellow animal; the Prêto, a black or dark animal; and the Ribanceria, or Rosilha, an animal with red roan coloring and white bands on the thorax (Hill, 1967). The strains in Brazil resemble mainly the Mehsana, Nagpuri, and Jaffarabadi breeds of India.

It is generally conceded that buffaloes will not cross successfully with cattle due to differences in number of chromosomes (48 vs 60). However, reports from China claim that a number of cattle-buffalo hybrids have been produced, and that they are superior to the buffalo in heat tolerance, milk yields and draft capacity. But these reports are yet to be confirmed.

MORPHOLOGY

Skin and Hair Coat Characteristics

Water buffaloes show various gradations of color within the range of grey to black depending upon breed (Cockrill, 1968a). Their skin may also exhibit gradual darkening with advancing age, particularly after the first five years. Skin character—color and texture—is one criterion for distinguishing various races. Some swamp buffaloes of China, Thailand, the Philippines, Indonesia, and other countries have unpigmented skin, which is called albinoid, although true albinism is

extremely rare This lack of pigmentation has been considered a recessive character The areas with the highest percentages of white swamp buffaloes are the Bali island of Indonesia (70%), the northern part of Thailand (30%), and Thailand as a whole (15%) In West Malaysia, Thailand, Indonesia, the Philippines, Vietnam, and Cambodia the incidence is around 5%, in Borneo and Nepal it is rare and in Taiwan it is less than 1% The higher percentage of white buffaloes in Bali has been attributed to the socio-religious factors since only the colored ones are slaughtered for food, while in Thailand selective breeding may account for it Albinoids are either rare or unknown in Burma and Hongkong and in the various breeds of river buffalo found in India, Ceylon, Pakistan, Afganistan, Egypt, and Yugoslavia With advancing age, the skin of the white buffalo becomes gradually spotted with round black or brown freckles, especially on the muzzle and nostrils In certain breeds of river buffaloes, which are normally black, a light brown skin color with some freckling is also occasionally found

During summer the color of Murrah buffaloes, housed indoors for two to three months, changes from black to copper brown or pinkish grey, but upon returning outdoors, the skin color returns to black within a few days A similar response to light exposure has been reported for Egyptian buffaloes The theory is that solar radiation influences the degree of skin pigmentation, perhaps by affecting the formation and activation of tyrosinase As in cattle, the dorsal areas of the body have the most pigment, the lateral body areas and extremities are intermediate, and the ventral and axillary regions have the least pigment This suggests that ultraviolet radiation may be concerned in melanin formation But how the heavy skin pigmentation may aid in its suitability to hot climates is not fully understood

The density of hair on the buffalo skin varies considerably with age, breed, season, and the extent to which the animal is housed It is very sparse compared to that of cattle In new born calves it is normally red or brown with a mixture of light grey and a good number of long black hairs In albinoids the hairs are yellow The average number of hair follicles per cm² of skin is nearly 400, compared to over 2000 in cattle, but the diameter of each hair is about twice that of cattle hair Maximum density of hair follicles occurs in the eyelids, carpal region, and switch Typically, the number of hairs per follicle is one, as in cattle, but two to four normal hairs per follicle may occasionally be seen in the region of the neck, flank, thorax, carpus, upper forelimb, vulva, and switch Neonatal calves have long, dense hair but density decreases with age The density of visible hair is also

subject to considerable seasonal fluctuation, being lowest in summer and highest in winter.

The thickness of the skin and its various layers varies according to age, sex, breed, and body region. The thickest skin is found in the neck. Buffalo skin is thicker than the skin of cattle (6.5 mm vs 4.3 to 5.5 mm). The thick skin may afford a certain amount of protection against overheating of the body through reduction of thermal conductivity, but it also restricts the dissipation of heat through convection and radiation.

Buffalo skin differs from that of cattle in the location, shape, and number of sebaceous glands per hair follicle (Hafez, *et al.*, 1955). The glands are more lobulated and well developed in buffaloes. Each hair follicle is encircled by two or three sebaceous glands, rather than one bilobed gland as in cattle. Well functioning sebaceous glands are no doubt an important adaptation to the buffaloes' semi-aquatic mode of life since the secreted sebum acts as a barrier to water absorption through the skin.

The average number of sweat glands per cm^2 of skin in buffaloes is much less than in cattle (<2100 vs >2500) but their circumference is greater (0.47 mm vs 0.26 mm). In buffaloes the maximum number are found in the neck and groin regions. The number of sweat glands per unit area like the number of hair follicles, decreases with age.

In spite of differences in the characteristic skin, hair coat, and body configuration of buffaloes and cattle, the body surface area per unit of mass is approximately the same for both species.

Blood Constituents

Data on certain morphological and chemical constituents of adult buffalo blood are listed in Table 16.2. In buffaloes hemoglobin concentration remains fairly constant during pre- and postparturient stages, while in cattle concentration decreases after parturition.

Values for hemoglobin, serum protein, and serum calcium are lower in buffaloes than in cattle, but the serum inorganic phosphorus is higher in buffaloes (Kehar and Murty, 1951). There does not seem to be any detectable difference in blood sugar and serum magnesium content of the two species. It is difficult to assess the significance of these findings on variations in blood constituents because few of the comparisons between the two species have dealt with animals similar in age and weight.

TABLE 16 2
Average values for various blood constituents of buffaloes

Item	*Indian*	*Egyptian*
Protein (gm/100 ml)	7 46 ± 0 09	7 43 ± 0 27
Nonprotein nitrogen (mg/100 ml)	–	36 00 ± 3 14
Blood sugar (mg/100 ml)	79 40 ± 3 1	81 40 ± 3 41
Sodium (mg/100 ml)	–	415 00 ± 6 53
Calcium (mg/100 ml)	10 00 ± 0 09	10 00 ± 0 16
Magnesium (mg/100 ml)	2 76 ± 0 10	–
Total phosphorus (mg/100 ml)	–	28 00 ± 1 03
Inorganic phosphorus (mg/100 ml)	6 95 ± 0 05	–
H b (gm/100 ml)	7 7 ± 0 22	12 98 ± 1 24
Lymphocytes (%)	–	51 00
Neutrophils (%)	–	36 00
Monocytes (%)	–	8 00
Eosinophils (%)	–	5 00
Basophils (%)	–	<1 00

Source Indian data from Kehar and Murty 1951 Egyptian data from Hafez and Anwar 1954

Physiology of Digestion

Buffaloes are favored over cattle by some because they seem to be better converters of feed (Alim, 1967, Hill, 1967, Cockrill, 1968b) However, this difference has not been entirely confirmed According to some reports, Zebu cattle have a greater dry matter intake per 100 kg body weight (2 51 kg) than buffaloes (2 37 kg) (Kehar, 1947, Sebastian *et al* , 1970) But Rao (1948) found buffaloes superior to the Zebu in this respect. Still others have shown no difference in the dry matter intake by the two species (Ichhponani and Sidhu, 1966, Whyte and Mathur, 1966) Johnson *et al* , (1968) did not observe any significant difference in the average dry matter intake between buffaloes and Holsteins with *ad libitum* feeding of guinea grass

Digestion trials have shown that on poor quality roughage buffaloes had a slightly higher digestibility of crude fiber and ether extract than cattle, but on good levels of feeding the average coefficients of digestibility for dry matter, organic matter, ether extract, crude fiber and nitrogen free extract appeared similar in both species Buffaloes do seem superior in ability to digest crude fiber and in retention of nitrogen, calcium, and phosphorus, which affords a nutritive advantage, especially under poor feeding conditions Apparently buffaloes can maintain themselves mainly on roughages with comparatively less concentrates than cattle However, on a diet of lucerne plus

concentrates the efficiency of feed conversion for milk production was 23.2% for buffaloes and 24.0% for Sahiwal cows (Sebastian *et al.*, 1970). These researchers concluded that with adjustments for differences in maintenance requirements the intakes per unit of solids-corrected milk were similar; consequently, without a differential in price for fat content of the milk (avg. 7.04% for buffaloes and 4.63% for cows), buffaloes would provide about 35% less return over feed costs than cows. But since there is a premium paid for fat content in most areas, the milk of buffaloes is competitive with that of cattle.

In spite of some conflict in findings, buffaloes are generally recognized as being superior to cattle in the utilization of crude fiber, ether extract, and calcium and phosphorus; inferior in the utilization of nitrogen free extract; and equal in the intake of dry matter, crude protein, and organic matter. The superiority of buffaloes over cattle in digestibility and efficiency of utilization of feed nutrients is manifested only when the two species are fed on a low plane of nutrition with coarse roughages as the main source of energy.

The bacterial and protozoal populations in the buffalo rumen are similar to those of cattle, but the buffalo has a higher concentration of total volatile fatty acids and acetic acid. The high fat content of buffalo milk may be attributed to the higher concentration of rumen acids (Ray and Mudgal, 1962). On low nitrogen intake the buffalo seems to recyle more urea nitrogen through the saliva (Pant and Roy, 1970a). This may be of significance if one accepts the theory that buffaloes fare better than Zebu cattle with adverse diets, especially when the diets are grossly deficient in nitrogen.

Examination of the feeding habits of the two species reveals that buffaloes are not as discriminatory in their feeding habits as cattle. They will consume poor quality pasture refused by cattle.

Buffaloes seem to adjust to seasonal variations in environmental temperatures by altering the proportion of energy yielding nutrients that they ingest, as evidenced by lower intakes of roughages during the summer months. They have about the same requirements of water per unit of dry matter intake as Zebu cattle (Sebastian *et al.*, 1970) but can tolerate a higher intake of fat.

With a rise in environmental temperature the abomasal secretion in buffaloes declines, and its acidity also decreases. At 40–42°C free hydrochloric acid disappears. Secretion may be restored by moving the animals into a cooler place; but wetting has proven more effective than putting the animals in shade. Thermal stress reduces the contractions of smooth muscle in all parts of the digestive tract. The rumen contractions declined from 193 to 35 after 8 hours at 40°C (Aliev, 1963). Also the passage of the digesta from the rumen seems

very much depressed by thermal stress Cooling the animals under a shower proved effective in quick restoration of function Intense solar radiation seems to influence the secretory activity of the pancreas and small intestine to a greater extent in buffaloes than in cattle, consequently heat stress appears to have an adverse effect on the efficiency of digestibility in buffaloes

Feeding Standards

Due to the limited research on nutrient requirements, there are no adequate feeding standards for the buffalo Lander (1949) suggested the following daily requirements from his own investigations and a survey of shed feeding practices in India

(1) *For maintenance*

Body weight	Dry matter (DM)	Digestible protein (DP)	TDN
400–500 kg	6 0–9 0 kg	0 367 kg	4 24 kg

For every 50 kg increase or decrease in body weight 0 5 kg of DM containing 0 03 kg DP and 0 32 kg TDN should be added or subtracted.

(2) *For production* For milk production Lander recommends the addition of 0 20–0 21 kg TDN containing 0 03 kg DP for every kilogram of milk containing 7% fat for every 0 5% below or above that fat content 0 01 kg TDN containing 0 001 kg DP should be subtracted or added These recommendations are somewhat lower than for cattle However, Whyte and Mathur (1966) are of the opinion that the nutrient requirements worked out for cattle are suitable for buffaloes That is, the requirements for maintenance and the first four to five liters of milk may be provided for an animal weighing about 400 kg and producing 1200–1600 kg milk per lactation by feeding 35–40 kg of Para or Guinea grass (10% crude protein) per day, plus about 1–2 kg molasses with 1–2 kg hay or straw, mineral mixture, and salt but no dry concentrate

Thermoregulation

The basic thermoregulation properties of buffaloes are similar to those of cattle (Chapter 3) But because of their coloring and skin characteristics, it is commonly believed that buffaloes are not well

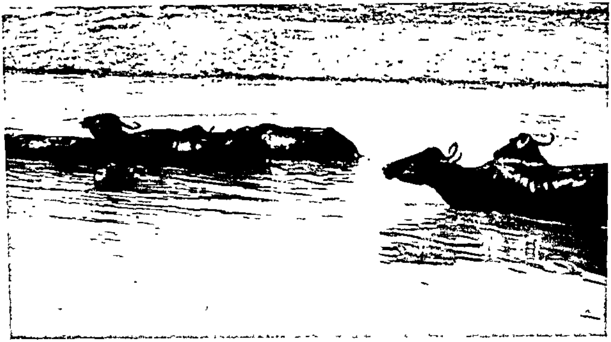

FIGURE 16.4
The buffalo has a very strong desire to cool itself by wallowing in ponds during hot weather. Muddy water is preferred to clean water.

adapted to the tropics. In Egypt it was found that the exposure to sun for two hours resulted in a rise of 1.3°C in body temperature for buffaloes, as compared to 0.2 to 0.3°C for cattle. Respiration rate was also much higher in buffaloes, and pulse rate increased in buffaloes but not in cattle. Under shade conditions, however, buffaloes have better heat regulating mechanisms than cattle. And buffaloes seem to respond less to high humidity than cattle; thus they may be superior to cattle in humid areas if they are protected from direct radiation. Although the prevailing concept is that buffaloes have a poor capability of sweating because of the low number of sweat glands, they have a good capability of sweating at high temperatures (Table 5.3). In spite of this capability, they much prefer wallowing during hot weather. It is common to see buffaloes wallowing in ponds during the hot summer months (Figure 16.4).

Male Reproductive Tract

The anatomy of the buffalo male reproductive tract is similar to that of cattle but the testes of the buffalo are smaller. The seminal vesicles in the buffalo are less lobulated and smaller—about one-sixth the size of those in the bulls. The smaller testes and accessory glands may account for the smaller volume of semen. The penis of the buffalo is about 10 cm shorter than the bull's. When adequately fed the buffalo has good libido.

Buffalo and cattle semen do not differ qualitatively in their biochemistry The slightly lower viability of buffalo semen when diluted with an extender and the lower recovery after freezing have been attributed to the higher level of phosphates and phosphatases in buffalo semen In both cattle and buffaloes, spermatogenesis is inhibited by high body temperature

PERFORMANCE

Viability

The buffalo has poor viability at young ages, with calf mortality often reaching 80% (Cockrill, 1966b) Data on 9475 births in 33 herds of cattle and 23 herds of buffaloes revealed the mortality of calves from birth to 2 months of age was 10 6 and 33 5% respectively (Dhanda and Khera, 1957) Season appears to have a significant influence on mortality, particularly in buffaloes While mortality in cow calves increased some in the monsoon, the losses of buffalo calves were high in both the monsoon and winter

Losses from gastrointestinal disorders, varying from acute indigestion to infectious scours, are also high—67 8% in buffaloes up to 3 months of age, as compared to 19 5% in cattle Digestive disturbances are more serious in buffalo calves weaned at birth (50% mortality) than in calves allowed to suckle their dams for 3 days after birth (15% mortality) Out of 4592 calves born alive in two herds of Egyptian buffaloes, 33% died before reaching 3 years of age Of these 81 8% died prior to 6 months, 10 9% between 6 and 12 months, 2 4% between 12 and 18 months, 1 3% between 18 and 24 months and 3 6% between 24 and 36 months (Asker and El-Itriby, 1957) A more recent study reveals that 70 5% died within 0 to 6 months, with 72 2% of the deaths due to digestive and respiratory infections (Shahin *et al*, 1967) Death rate appears higher in males than in females This may be more because of preferred treatment than inherent sex weakness

Such poor viability has been a major handicap in improvement by selective breeding in buffaloes Amongst the various factors responsible for mortality, poor hygiene and nutrition and very early weaning have been most significant. It is possible too that the high fat content of buffalo milk is responsible for the frequent occurrence of digestive disturbances There is little information to indicate how buffalo calves differ from cow calves in susceptibility to various diseases

Birth Weight

The birth weight for buffaloes is, in general, higher than for cattle indigenous to the tropics. Birth weight is influenced significantly by sex, parity number, breed, nutrition of the dam, and season. Differences due to sex are about the same as for cattle, with males being 0.4 to 4.0 kg heavier than females. Birth weights show a progressive increase up to fourth calving. The Beheri of Egypt appears among the largest in birth weight; the breeds of southeast Asia are intermediate; and the Carabao the smallest (Table 16.3). While workers in Egypt did not observe any influence of month of calving, Misra *et al.* (1970) reported a higher birth weight for calves of Indian breeds born in summer than for those born in the monsoon and autumn seasons. There is also evidence of differences among sire groups (Asker and Ragab, 1952). The heritability estimates for birth weight range from 0.08 to 0.56 and the repeatability estimates from 0.45 to 0.58.

TABLE 16.3
Birth weights (in kilograms) for buffaloes in various locations.

Breed	*Location*	*Male*	*Female*	*Range*
Beheri	Egypt	40.7	37.9	30.0–42.2
Murrah	India	31.0	28.3	23.7–37.0
Murrah	Pakistan	33.4	30.7	26.1–39.4
Murrah	Thailand	31.5	27.6	–
Carabao	Taiwan	25.0		–
Italian	Italy	38.7	35.5	34.5–43.6

Twenty-four studies of sex ratios in five countries gave the average percentage of males as 51.4%, with a range of 48.2 to 56.8% males. Most reports state that the sex ratio did not vary significantly from 1:1. In all breeds of buffaloes the incidence of twinning is low—0.3%, as compared to 1.5% for cattle.

Age at Puberty

Buffaloes reach puberty rather late. The Egyptian buffalo averages 406 days (range 347 to 684), with the average age at conception 647 days (range 406 to 812 days) (Hafez, 1955). When buffalo heifers are mated at puberty there is a high incidence of abortion or death of

calves within 7 days of birth. Even when calves have been carried to the term, the mammary glands remain underdeveloped resulting in less milk production. Although a buffalo can conceive as early as 647 days (21.5 months), the full reproductive efficiency is not attained until about 6 months later. In India, it is recommended that buffalo heifers be bred at 24 to 30 months, yet most do not conceive until 33 to 36 months of age. There is no information available on breed differences in the age of puberty although wide individual variations have been observed.

While improving the nutritional status may considerably affect the age of puberty, little is known about its heritability. One estimate on heritability of age at first conception for Murrahs was 27.4% (Singh and Dutt, 1964). However, this rather high value must be interpreted with caution since the heritability was estimated through doubling the simple regression of daughter on dam—that is, by repeating the dam's record with each daughter's record—rather than by intra sire regression of offspring on dam or halfsib correlation methods, due to the small number of sires. It has been recommended that calves be selected on birth weight to overcome the problem of late maturity since there seems to be an inverse relationship between birth weight and the period of first calving in Murrah buffaloes (Goswami and Nair, 1965).

In India the average age of puberty of buffalo bulls is around 2 years (Kartha, 1959), but they are used for service at 3 to 3½ years of age in both India and Pakistan. This is somewhat later than for cattle. The average age at first service for Egyptian buffaloes has been 3.7 years, while in Italy and the USSR bulls are put to service at around 2 years of age.

Age at First Calving

In spite of the buffalo's late sexual maturity and longer gestation period, its average age at first calving does not greatly exceed that of Indian cattle. The average age of first calving for 629 buffalo cows in various state government farms of India was 40.4 months, with 89% of the calvings between 30 and 48 months, 3% between 28 and 30 months, and another 3% between 50 and 52 months. Other statistics have shown averages of 46 months in India (range 41 to 51 months), 47 months in Pakistan (range 32 to 72 months) (Ashfaq and Mason, 1954), and 39 months in Egypt (range 22 to 60 months).

Age at first calving does not appear to be influenced by sire, but 12% of the variance for the trait has been reported to be due to mater

nal effects (Sidky, 1951). Using intra-sire regression of daughters on dams Asker *et al.* (1953) found the heritability to be 13%. Season of birth has a significant influence on the age at first calving; females born in the fall months have a greater chance of calving earlier than those born during other seasons of the year. The Egyptian data may possibly have some bias inasmuch as the breeding policy is to take full advantage of the Berseem clover season in late winter and early spring. On the other hand, most buffaloes tend to have more frequent estrus from September to November; therefore, age at first calving, instead of truly being a function of age, is also determined by the season of attainment of puberty. The average age of first calving is higher (47 to 52 months) in village buffaloes than in well fed farm animals (42 to 49 months), which indicates that plane of nutrition affects this trait. Such large variations suggest the possibility of reducing the age at first calving by proper feeding and management. Selection for early maturity might also tend to reduce age of calving provided it is established that heredity influences the age of puberty. No doubt some improvement could be attained by close attention to estrus as buffaloes are subject to anestrus, especially during the hottest portion of the year.

Season of Calving

Although buffaloes may breed year round, breeding is more frequent in certain periods. In the Philippines a seasonal trend of reproduction has been observed, with highest sexual activity coinciding with the rainy and cooler months (August to January). In India 15 investigations indicated an influence of season on the incidence of estrus and calving of buffaloes in various regions. One survey of 680 females on government farms and 475 village animals showed that 70% of the buffalo cows and heifers calved between August and November, and less than 5% during the summer months, April to July. Numerous writers have described the buffalo as a seasonally polyestrus animal, showing estrous cycles for a period of eight months but being sexually inactive from March to June. In Bulgaria, maximum ovarian activity coincides with the autumn and winter months, and in Italy the majority of calvings occur between July and October.

No doubt season of calving has an influence on the onset of first postpartum estrus, either directly, through climatic stress, or indirectly, through feed supplies. In Egypt the average period between parturition and first estrus was 35–45 days for buffaloes calving during the winter season when Berseem clover was available, in contrast to

140–160 days for those calving May to October Similar seasonal contrasts have been observed in India Winter calvers (November to Feburary) averaged 87 days for first postpartum estrus, as compared to 115–170 days for those calving in other seasons Because of the wide seasonal variation, it is virtually impossible to discern if there are characteristic breed differences Reports from the Philippines give an average for the Carabao as 44 days during all seasons, which suggests some advantage over breeds in India and Egypt, but the average value for grade Murrah buffaloes in the Philippines is 47 days

Estrous Cycle

The average length of the estrous cycle in buffaloes is about 21 days, but it shows more variability than in cattle In India the mean length of the estrous cycle in Murrah heifers was 19 3 days, while in cows it was 22 9 days (Rao and Murari, 1956) Apparently the cycle length is not influenced greatly by breed or season

The duration of estrus for the Egyptian buffalo shows considerable variation ranging from 12 to 60 hours with a mean of 28 4 hours, while the Philippine Carabao has a more intense estrus lasting 24 to 36 hours with a maximum of 4 to 5 days Although the estrus behavior of buffalo females resembles that of other livestock, it has some distinct characteristics For instance buffaloes show little mucous discharge because of increased frequency of urination while in estrus For the majority of cattle estrus begins in the A M, but for buffaloes it begins most frequently in the P M (84% 6 P M to 6 A M) The buffalo is more of a nocturnal breeder than cattle In general the signs of estrus seem less intense in buffaloes than in cattle although certain buffaloes exhibit a high degree of estrus receptivity The vaginal smear differs considerably from that of other livestock in that it does not show clear cut changes at different stages of the cycle, either because of the fluctuation of the hormone level throughout the cycle, or because of the complex nature of the vaginal epithelium Recently, it has been found that on the basis of the changing crystallization pattern of cervial mucus of Murrah, five stages of heat can be identified (1) early heat, characterized by medium fine ferns with typical cellular infiltration, (2) mid heat, showing a typical fern pattern, (3) heat, exhibiting slight cellular infiltration (4) late heat, having extensive cellular infiltration masking the fern pattern, and (5) off heat, characterized by only cellular infiltration (Roy *et al* , 1968)

The time of ovulation in relation to estrus is still obscure in the buffalo, but there is reason to believe that ovulation occurs within the

estrus period since the percentage conception of buffalo cows served during different phases of heat was highest (93.0%) during heat and lowest (33.0%) during late heat. The ovulation time in Egyptian buffalo cows ranged between 18 and 42 hours after the first appearance of heat symptoms (Shalash, 1958); while in Indian buffaloes ovulation occurred from 25 to 34 hours after the onset of heat or within 10 hours after the cessation of heat. Age, level of milk yield, and work do not appear to influence time of ovulation.

The incidence of silent heat is fairly common in buffaloes and silent heat seems to prolong the subsequent cycle length. Of 502 cycles in 263 buffalo females the percentages of short cycles (up to 12 days), normal cycles (13–24 days), and long cycles (25–50 days) were 16.4, 48.3, and 35.3%, respectively. The long cycles were attributed to silent heat (Roy, 1969).

Gestation Length

The average gestation length for buffaloes is considerably longer than for any breed of cattle (Anderson and Plum, 1965), averaging between 305 and 316 days. The length of the gestation period is influenced by the sex of the calves, the male calves requiring a significantly longer period than female calves. There are also indications of effects of sire, age of dam, size of dam, size of calf, parity number, and season, with the period increasing during the fall months as compared to spring and winter.

Services For Conception

Information available on the conception rate in buffaloes, either by artificial insemination or by natural service, is not sufficient to arrive at a definite conclusion; however, where comparable data are available, the conception rate of buffaloes seems to be as good as that of cattle. With natural service it has been reported to by 63.0% conception for first service. Following artificial insemination in 102 animals of the Murrah breed, the average percentages of conceptions that required one, two, three, or four and more inseminations were 66.2, 21.6, 5.4, and 6.8%, respectively, and the average number of inseminations required per conception was 1.56 (Bhattacharya, 1962). In the Egyptian buffalo conception rate following first service has been reported to vary from 36 to 46% and the average services per conception from 1.4 to 2.1. Month of calving appears to affect the num-

ber of inseminations per conception, with the number of services highest (2.8) in summer and lowest (1.5) in autumn. As in cattle, age also affects this characteristic. Virgin heifers have a higher breeding efficiency than cows, but females in first lactation require more services per conception than older animals. The best time of post partum breeding is about the same as for cattle, 51 to 100 days. The low repeatability for services per conception (0.083) indicates that this trait is predominately influenced by environment.

Service Period

The length of service period is highly variable as indicated by the following:

Breed	*Location*	*Average*	*Range*	*Author*
Native	India	168	65–201	Rai 1966
Murrah	India	180	21–202	Rife 1959
Egyptian	Egypt	165	9–632	El Sheikh 1967

In contrast, the average service period for buffalo cows in the USSR is given as 20–40 days. The differences among estimates are probably due both to managerial and climatic variations. Anyhow, buffaloes in warm climate areas tend to have longer breeding periods than cattle, no doubt because of the incidence of silent heat, anovulatory heat, infertile services, and embryonic mortality. The influence of climatic stress on the exhibition of heat symptoms and the incidence of prenatal mortality in buffalo cows and on the semen characteristics of bulls also needs careful appraisal.

Calving Interval

Irrespective of breed, parity, month and season of calving, the average calving interval derived from 37 studies, principally of four breeds, in Ceylon, Egypt, India, Malaysia, Pakistan, Philippines, Thailand, Brazil, and Trinidad was 495 days, with herd averages ranging from 403 to 730 days. There was no distinct relationship between calving interval and location or breed.

Among the factors influencing the calving interval are the level of milk yield, the month of calving, the season of calving, and the sequence of calving. According to Basu (1966) high milk production

delays the occurrence of the first postpartum estrus, thereby influencing calving interval as indicated below:

Lactation milk yield (kg)	*Calving to first estrus (da)*
0–909	125
910–1363	169
1364–1818	187
>1819	226

As pointed out in Chapter 12, the negative energy balance usually occurring in the early stages of lactation no doubt contributes to the delay in the onset of estrus. Tomar and Tomar (1960) reported that rainy season (July to October) calvers had a significantly shorter calving interval (461 days) than summer calvers (529 days), although the month of calving was not significant; but others have not found any influence of season on calving interval. In addition to the season of calving, sequence of calving is known to influence this trait. The interval between first and second calvings is longest—about 530 days—and the subsequent intervals tend to decline, the interval between second and third calving averaging 495 days and later intervals, 460 days (Desai and Kumar, 1964). Similar trends have been observed in Zebu cattle of India, but the decline is not as marked in temperate zone cattle although the first interval is significantly longer.

The fact that the heritability and repeatability of calving interval

TABLE 16.4
Summary of reproductive characteristics of buffalo females.

Trait	*Average*	*Range*
Age of puberty (days)	400	330–700
Age of first calving (months)	45	40–52
Estrous cycle (days)	21	18–24
Duration of estrus (hours)	24	20–28
Ovulation after end of estrus (hours)	10	5–24
Silent heat, one (%)	25	15–35
Silent Heat, two in succession (%)	10	9–11
Gestation length (days)	315	295–330
Months of highest frequency of calving	–	Aug.–Dec.
Rate of involution of uterus (days)	<40	15–67
First postpartum estrus (days)	90	35–170
Service period (days)	167	71–238
Calving interval (days)	495	403–730

are negligible indicates that this character is almost entirely determined by environmental factors The repeatability estimate of calving interval in Bhadawari buffaloes is about 0 198, while the heritability in the Murrah breed has been given as 0 028 (Dhinsa, 1963) Similar low repeatability and heritability estimates of this character have been reported from Egypt, Italy, and Pakistan In Pakistan it was demonstrated that the calving interval in buffaloes could be reduced from 614 to 385 days by improving herd management Table 16 4 provides a summary of present knowledge about reproductive characteristics of buffalo females

Longevity

The average productive life of the Egyptian buffalo has been estimated as about 5 lactations (Alim, 1953) However, others report length of productive life as low as 3 5 lactations, and some estimates of total herd life range from 7 to nearly 11 years As in cattle there is a low correlation between age of first calving and length of productive life

According to Cockrill (1968a) the longevity of the swamp buffalo is remarkable It is not uncommon to find animals working at 25 years of age In Balkan countries there are numerous instances of buffaloes living to the age of 40 years

Milk Yield

For the Indian subcontinent and certain other regions the buffalo is the main dairy animal In India milk yield of the average buffalo is almost twice (682–727 kg) that of the average Zebu cow (364–409 kg) Both in India and Pakistan the best herds are found at military farms and milk colonies On four farms in Pakistan the average milk yield was 1858 kg and on five farms in India the average yield was 2052 kg (Rife, 1959) From most reports it appears that in these two countries about 3% of the yields exceed 3500 kg in one year or less and approximately 2% of the yields are less than 100 kg The difference in average yield between the buffaloes in the villages and on the government farms is most likely due to environmental factors as some of the animals on the military farms and all those in the milk colonies are purchased from the villages

The average yields in Egypt are similar to those of India and Pakistan, the average milk yield of village buffaloes is about 800 kg

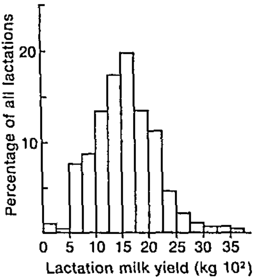

FIGURE 16.5
Distribution of lactation milk yield by 250 kg intervals for 700 lactations of buffaloes in Egypt. (Data from Sidkey, 1950).

and that of government farm herds about 1700 kg. Figure 16.5 illustrates the variability in lactation yield by 250 kg intervals for 700 lactations over a three year period on government farms in Egypt. For Italy the average first lactation yield is around 1650 kg.

The swamp buffalo of southeast Asia and the Carabao are poor milkers in comparison to buffaloes in India and Egypt. Average yields for the Carabao are from 100 to 400 kg per lactation.

No doubt there is considerable variation in milk yield due to environmental conditions, but the wide range in yields for individuals suggests ample genetic variability for selection for higher milk production. Currently efforts in this direction are not as extensive or as well organized as for cattle. On the government farms no male calves are saved for breeding from dams that produce less than 2000 kg; but this is about the extent of selective breeding as there are few progeny tested sires. A large number of male calves have been distributed from these herds for use in the general population. The influence is unknown, but with the low selection differential and lack of progeny tests it is doubtful that the genetic potential of the males distributed is much superior to the average of the population.

There has been considerable seasonal variation in milk production on farms in Pakistan, with the highest yields coming from cows calving in November and December. However, claims about the influence of season of calving on milk yield are conflicting. Some concur with the results from Pakistan, while others have observed no effect of season of calving on total milk yield. Still others suggest that summer calvers yield significantly more milk than monsoon or winter calvers (Desai and Kumar, 1964; Singh, 1966). In Egypt the month of calving had less influence on milk production than in India, but autumn and winter calvers had slightly higher production and longer lactation periods than cows calving in spring and summer (Ragab *et al.*, 1954).

In Egypt, age of first calving had a significant positive correlation with total milk yield in the first and the subsequent lactation periods up to the fourth Similar observations have been made by some in India, while others, such as Dutt *et al* (1965), have found a significant negative correlation between age at first calving and milk yield up to 10 years of age and a positive correlation between age at first calving and life time production In view of these conflicting claims it is premature to suggest a selection and breeding program based on the age of maturity

As with cattle, total milk yield appears to increase with advancing age, and maximum production occurs in the third or fourth lactation There is some evidence that the decline in the milk yield of buffaloes with advancing age beyond 6 years is much greater than for cattle However, more data are needed to confirm this and to establish age correction factors for the buffalo

Basing their conclusions on the intra sire regression of daughters on dams, Asker *et al* (1953) reported that the heritability estimate of milk production in the buffalo was 0 24 According to Ashfaq and Mason (1954) the heritability estimate of milk yield was 0 18 The repeatability estimates vary from 0 37 to 0 50 Both the heritability and repeatability estimates are similar to those for cattle, which means that the methods of selection and improvement already in practice with dairy cattle should be equally applicable to buffaloes

Milk Constituents

The milk fat percentage of buffalo milk is about twice that of cattle milk 6 8–7 2% in Murrah buffaloes in India, 6 5–7 0% in Pakistan, 7 2–7 9% in Italy, 6 4–7 1% in Egypt, 7 0–10 0% in the USSR, 7 5% in Bulgaria, and over 10 and 12% in the Philippines and China, respectively On occasion it may be as high as 15% with the overall average of about 7% or a little more (Cockrill, 1967) It varies with the age, season, and time of milking (Amble and Jacob, 1960) There is also considerable breed variation, the Bhadawari breed of India being the highest (13%)

Due to the high fat content, the total milk fat yield compares favorably with that of European cattle and is much higher than for indigenous cattle The repeatability estimate of total butterfat yield per lactation is approximately similar (0 43) to that for cattle and indicates that butterfat yield is a permanent characteristic of the individual cow (Knapp, 1957)

The other constituents of buffalo milk also differ considerably

from those of domestic cows. Buffalo milk is richer in total solids, minerals, and calcium and phosphorus and exhibits certain other differences in physical and chemical properties (Laxminarayana and Dastur, 1968). A summary of the constituents of buffalo milk in various countries as well as cow milk in India and the U.S. is found in Table 16.5.

With advancing lactation the fat content increases while the specific gravity and solids-not-fat behave in a reverse order (Ghosh and Anantakrishnan, 1964). In spite of the higher fat content, the phospholipid and cholesterol contents of buffalo milk are lower than those of cow's milk, while the total saturated fatty acids are higher, giving rise to a significantly lower iodine value. Also the milk protein of buffalo milk contains greater proportions of casein and slightly higher amounts of albumin and globulin than cow's milk. There do not seem to be quantitative and qualitative differences in the amino acid composition of casein, but the amino acid composition of the proteose-peptone content shows some quantitative differences from cow's milk. Buffalo milk is lower in sodium (47.7 mg%) and chlorine (66.98 mg%) than cow's milk (55.3 mg% and 85.6 mg%). There is no difference in the concentration of other minerals, except phosphorus, which appears higher for buffalo (0.107 g%) than for cattle (0.083 g%). Buf-

TABLE 16.5
Milk constituents (in percent) of buffalo and cow milk.

Breed	*Country*	*Specific gravity*	*Fat*	*SNF*	*Total solids*	*Protein*	*Lactose*	*Ash*
			BUFFALO					
Nondescript	India	–	7.62	9.61	–	3.91	5.70[a]	–
Murrah	India	–	7.16	9.21	16.41	3.35	4.81	0.765
Murrah	India	–	6.80	9.39	17.00	3.41	4.92	0.789
Murrah	USSR	1.031	8.10	–	18.10	4.32	4.90	0.840
Murrah	Bulgaria	1.031	7.50	9.88	17.38	4.10	4.78	0.730
Murrah	Italy	1.034	7.90	10.40	18.30	4.73	4.97	0.750
Murrah	Egypt	1.034	7.14	10.03	16.40	3.87	4.99	0.790
			CATTLE					
Nondescript	India	–	5.61	8.70	14.30	3.01	4.79	0.725
Red Sindhi	India	–	4.92	8.49	13.44	2.85	4.58	0.752
Holstein	U.S.	–	3.53	8.54	12.07	3.08	4.78	0.680
Jersey	U.S.	–	5.37	9.54	14.91	3.92	4.93	0.710

[a]Including ash.

falo milk generally contains more lactose and slightly higher amounts of citric acid (0 245 vs 0 183 g/100 ml)

Analysis of the vitamin content has shown that while buffalo milk contains many of the B complex vitamins and vitamin C and is as good in its vitamin A potency as cow's milk, it is characterized by the absence of carotene This latter characteristic has sometimes been used as a means of differentiating between milks

Buffalo milk is considered superior to cow's milk for making ghee in India or *semma* in Egypt In Italy buffalo milk makes the best Mozzarella cheese and is preferred elsewhere, for example, in the Philippines, for making soft cheeses However, it is not as good as cow s milk for the preparation of hard cheeses, such as cheddar, because of a slower rate of acid production, lower retention of moisutre in the curd, and higher losses in the whey In the preparation of infant foods, buffalo milk must be adjusted in its composition with the addition of phosphate and citrate and the curd tension reduced by heating

Temperament

In comparison to Indian cattle, buffaloes are very docile Due to their extreme submissiveness, their care is generally entrusted to children (Figure 16 6) By contrast, in Egypt buffalo cows may be very

FIGURE 16 6
Because the buffaloes of southeast Asia are very docile their care is entrusted to children

temperamental. They must often be hobbled to prevent them from becoming destructive, especially when strangers venture near.

Compared to the native Indian cow the buffalo is easier to milk because its calmness permits better let-down of milk. And the presence of the calf is not required to stimulate milk let-down. This may be done by gentle massaging of the udder and teats, principally the latter. More time is required for stimulation (2.5 to 3.0 minutes) than for European breeds of cattle (1.0 minute). Since the stimulation requires considerable time and to avoid calf feeding, a large proportion of buffaloes in India are milked with the calf present; but this is not always the practice in the milk colonies.

Draft

Where speed is not the criterion buffaloes are efficient work animals. In the lowland rice growing areas they are much preferred as their massive feet aid in puddling the soil. The exceptionally flexible fetlock and pastern joints of the swamp buffalo enable it to move more efficiently in mud (Cockrill, 1967). Buffaloes are also preferred for threshing rice where trampling is used, and they perform such tasks as operating water lifts for irrigation better than cattle.

Buffaloes are less efficient than cattle as draft animals on hard surfaced roads because of their slower movement (3.2 km/hr) and inefficiency in withstanding dry heat and solar radiation. Nevertheless, they are used for heavy loads as a team is capable of pulling almost twice as heavy loads as a team of bullocks. Female buffaloes are used for field work, whereas female cattle are seldom put to work. It is claimed that female buffaloes can be worked 3 to 3.5 hours per day without adverse effect on milk yield.

Meat Production

Thus far little attention has been given to the buffalo as a meat producing animal. Buffaloes are seldom reared and fattened for meat production, but they are slaughtered for meat when they have outlived their utility as milk or draft animals.

Up to 52 weeks buffaloes grow more slowly than cattle. During this time the body weight of grade European breeds of cattle and even calves of indigenous breeds of cattle increases tenfold while the body weight of buffalo calves increases about eightfold. In India, Murrah heifer calves showed weight gains similar to those of cattle up to 6

months, but at 1 year they were 40 kg below the accepted standard of 250 kg for buffaloes. Buffaloes make slow gains in the early weeks of life but by 20 weeks of age gains may exceed 0.6 kg/day. At 1 year of age the Egyptian buffalo heifers seem more nearly like Jerseys and grow at about the same rate until 2 years of age, but the Italian buffaloes grow at about the same rate as Holsteins (Knapp, 1957).

The dressed carcass weight of even a moderately fattened buffalo will not be more than 48% of the live weight, while one in poor flesh will dress out at 35%. This is because of the large digestive system, bones, and head (Cockrill, 1967). However, in Italy, Bulgaria, and Yugoslavia a dressed carcass weight of over 50% is not uncommon. The forequarters of buffaloes are larger than those of European breeds of beef cattle. The carcass fat has a low melting point (36–37°C). The percentage of lean meat is good (79), but the percentage of bone is high (19–21).

An experiment conducted in Egypt indicated that growth rate, dressing percentages, and carcass quality, as judged by the proportions of lean and fat, are good (Table 16.6). As expected, the quantity of fat was highest in steers and lowest in young calves. The color of the meat darkened with age and the lean of the steers was lighter in color than that of the bulls. Tests showed that tenderness decreased with age. Because of toughness the meat of both steers and bulls slaughtered at 24 months of age was considered unacceptable to consumers.

TABLE 16.6
Composition of buffalo carcasses in relation to age and live weight. All animals were started simultaneously and three animals were slaughtered at each of the ages indicated

Type animal	*Age slaughtered (mo)*	*Live[a] weight (kg)*	*Dressing (%)*	*Live weight to carcass (%)*		
				Lean	*Fat*	*Bone*
Calves	1.5	74	59.9	35.4	3.3	13.0
	6	158	57.2	34.0	2.8	11.8
Bulls	12	230	53.7	32.6	5.7	9.9
	18	359	57.6	33.4	6.7	9.3
	24	449	52.7	33.7	6.1	7.8
Steers	12	236	53.3	31.2	7.3	9.1
	18	360	54.4	34.8	7.2	9.3
	24	450	54.3	34.1	7.7	8.9

Source: Adapted from Ragab et al., 1966.
[a] Average for three animals.

In older buffaloes (>18 months) the muscle fibers are thicker with more nuclei. In transverse section the fibers are polygonal and not irregular shaped and the fibrillae are larger with greater cell content than in cattle. There is little or no marbling. The fat is laid down as external covering, between the muscle bundles and in the viscera. These qualities make the meat coarse. However, the meat of 4- to 6-week-old calves fed properly is similar to veal. In Italy, Bulgaria, and Yugoslavia the quality of buffalo meat is good and the flavor is indistinguishable from beef. In the absence of carotene, the fat is pure white. In parts of Nepal and Thailand the hide is processed for eating by prolonged boiling and subsequent drying in the sun. After cooking in the fat it makes delicious "buffalo chips."

The price of buffalo meat is usually competitive with beef, and buffaloes can be slaughtered at a younger age (2.0–2.5 yr) than cattle (>4 yrs).

Susceptibility to Disease

Although buffaloes suffer from almost all the diseases and parasitic infestations common to cattle, there are certain differences in identity, prevalence, clinical picture, and susceptibility to various infections (Mohan, 1968). It is claimed that buffaloes are less susceptible to rinderpest but this may not hold for all areas. Reports from India and Indochina suggest that the buffalo is less susceptible to foot and mouth disease and clinical attacks are milder; but in Malaya, the Philippines, and Laos the incidence and severity of infection seems no less than in cattle. Brucellosis is more sporadic in buffaloes. They are very susceptible to hemorrhagic septicemia. They appear less susceptible to Johne's disease, salmonella, and other enteric infections, but the incidence of tuberculosis is variable. While there is some evidence that Egyptian buffaloes possess resistance against tuberculosis, the incidence of infection is much higher in Indian buffaloes than in native cattle, possibly because of the large numbers of buffaloes kept in dark, damp housing around urban centers.

Among the parasitic diseases, ascariasis is very common in buffalo calves and is one of the main causes of mortality. Prenatal infection is invariably found. Although the species of ticks that infest buffaloes are generally the same as for cattle, tick infestation is usually lighter and the tick-borne diseases are much less common than in cattle (Cockrill, 1967), probably because of the difficulty in penetration of the hide by ticks.

THE FUTURE ROLE OF THE WATER BUFFALO

The future of the water buffalo has been a subject of great controversy There are strong opinions for and against buffaloes Some countries have gone so far as to develop plans to eventually replace buffaloes with cattle It is difficult to predict how the trend will go Conceivably, well executed programs in cattle breeding and the development of suitable machinery for lowland rice production could both have marked influence on the buffalo population

The use of the buffalo varies from place to place While in southeast Asia it is used primarily for agricultural power in paddy cultivation, in India, Pakistan, and Egypt it is more important as a dairy animal In India the Kaira cooperative at Anand in Gujrat State is a testimony to the importance of buffaloes in meeting the country's vast needs for milk products Besides supplying nearly 100,000 kg of milk daily to the city of Bombay, this plant also manufactures varying quantities of clarified butter (ghee), milk powder, baby food, cheese, condensed milk, and casein

Presently the rural populations in India and Pakistan maintain cattle primarily to obtain a pair of bullocks, but with the consolidation of land and increasing mechanization the need for bullocks will no doubt decrease It would be logical to assume that with advancing mechanization buffaloes will also decrease in importance for power However, this does not mean that buffaloes will be entirely replaced by machinery Whether they can remain competitive in milk and meat production is uncertain In Yugoslavia, Bulgaria, and Malaysia, attempts to use buffaloes for meat production have had encouraging results Such investigations are important to India where there are cultural inhibitions against eating beef Development of a sound meat industry for India would not only help meet protein needs but could also serve as an earner of foreign exchange

One of the problems that will have to be solved is the high incidence of calf mortality At present the majority of buffalo calves are born during the monsoon season in southeast Asia Whether the high incidence of mortality in buffalo calves is due to their greater susceptibility to diseases than Zebu calves or to the season of their birth is undetermined. It would not be surprising to find that the mortality rate in Zebu calves born during the rainy season is much higher than at other times The present statistics may be misleading because about 75% of the calvings for buffaloes occur in the unfavorable environment, as compared to about 25% for cattle The poor hygienic conditions during the rainy seasons, along with increased

parasitic and other infections, appear to be the major causes of such high death rates in buffalo calves.

Another problem in developing a meat industry from this species is its slow growth rate. But feeding may be partially responsible for this. While Zebu male calves are fed reasonably well because they are potential bullocks, buffalo calves seldom receive similar care. And no doubt the customary early weaning of buffalo calves retards their development.

When one considers the merits of the buffalo as a dairy animal one confronts certain biases for moves to eliminate them. On the credit side, it is docile, thrives reasonably well on coarse roughages, already contributes significantly to the dairy economies of several countries, and provides a milk that permits a greater degree of toning. On the debit side, it is considered a semi-aquatic animal of nocturnal predilections, which matures slowly, breeds seasonally and seems less adaptable to the adverse climatic conditions prevailing in tropics. The latter may not necessarily be true as distress in buffaloes is manifested principally when they are prevented from seeking protective shade. In spite of these limitations, most of which are open to question, the fact remains that the buffalo has as good milk producing capacity as indigenous cattle and is thus a major economic asset to the peasant producer. In India, for instance, where the best milking breeds are found, the buffalo already contributes at least 60% of the total annual milk yield. This is in spite of the fact that most planned programs are oriented towards cattle.

No doubt the seasonality of breeding can be corrected largely through management. Recent experiments in India indicate that much can be done in this regard. It was found that all buffaloes that calved prior to the onset of winter (December) came into heat during the height of the summer season (April–June) if they were maintained in shaded half-wall sheds, where the ambient temperature was only 1.5°C below that outside. It was also observed that buffaloes maintained in a yard that afforded very little protection from solar radiation came into heat, as evidenced by the changing crystallization pattern of the cervical mucus. These cows were bred with reasonable success. Hence improper heat detection or failure to detect heats may be the main cause of low fertility during the summer months (Roy *et al.*, 1968). Housing of buffalo bulls during the summer aided materially in the improvement of semen quality and libido.

To ascertain the efficiency of summer breeding operations of buffaloes, Indian researchers maintained groups under the following treatments from April to June: (1) under conventional practice where the animals were sent out for grazing in the day (control group);

(2) under a shed during daylight hours, or (3) under a shed where provision existed for splashing of water over the animals at 10 00 A M , 1 00 P M , and 4 00 P M

In the control group a teaser bull accompanied the herd at all times Females found in heat were hand mated to a bull kept in a conventional half-walled shed In the other two groups estrus was detected by using a bull housed in a shed with provision for cooling the inside temperature to around 36°C The bulls were allowed to mate those they detected The respective calving percentages were. 14, 60, and 80% The percentages found in estrus were 50, 90, and 98%, respectively The loss of libido of the teaser bull and the gross deterioration in the semen quality of bulls when protection was not provided against climatic stresses were considered responsible for the poor fertility in the control group (Roy, 1969) Subsequent investigations have revealed that even provision of tree shade during the day is sufficient to prevent prenatal mortality

During the course of these investigations it was observed that estrus in buffaloes as compared to Zebu cattle was very weak even during the height of breeding season (August–December), while during the summer months (April–June) the symptoms became weaker They were depressed to such an extent that routine management practices would be inadequate in detecting heats The condition was indistinguishable from anestrus Moreover, use of teaser bulls seemed of doubtful value in detecting animals in heat as they lost libido when subjected to direct and indirect effects of solar radiations in the summer season But examination of cervical mucus crystallization pattern twice daily at 7 00 A M and 7 00 P M , or of genital tract by rectal palpation, or detection by leading a tethered bull (kept protected from summer stresses) three times a day at eight-hour intervals clearly indicated that there was no suspension of reproductive rhythm during summer The results of these investigations seem to contradict the prevailing view that buffalo cows pass into a condition of anestrus or subfertility during the summer months It is easy to conceive a variety of factors that make autumn (October–November) the season of highest conception The animals calve maximally during July and August By October–November they are probably beginning to gain in weight, with grazing at its best The buffalo bull, no matter what the housing may be during the summer, regains full sexual vigor by autumn as a result of the higher availability of nutrients during the previous three months (rainy season) and the more favorable climatic conditions

Another argument against the use of buffaloes is that it is possible to increase milk production through crossbreeding of indigenous cat

tle with exotic breeds. To what extent this argument can be translated into practice cannot be forecast for all situations. Moreover, if it is conceded that the dairy industry must be supported with indigenous resources, the extent to which crossbreeding among cattle groups can be carried out remains open to question. In spite of the current "green revolution" the general economic status of the average farmer in most areas of southeast Asia will remain rather low for a considerable time. For livestock this means the farmer will not have the wherewithal to produce crops for feeding livestock. Consequently, most animals will continue largely as consumers of agricultural wastes. These considerations will always limit the introduction of improved stocks. On this basis it could be argued that in the long run those species and breeds which demand less attention for housing and management and are less discriminatory in their feeding habits should prove more desirable.

Apart from the scientific considerations, there are social considerations that cannot be ignored in assessing the future of the buffalo. Human likes and dislikes will always have a say. Just as the relative popularity of tea and coffee in the various countries of the globe is largely dependent on the palate of the people, so is the desirability of cow versus buffalo milk. In rural India the place of the buffalo is relatively secure on this account. It is only around big cities and industrial belts where, instead of milk per se, the protein becomes important as a commodity, that milk from crossbred cows may catch the imagination of the trade for highest yields of protein, which is at present mostly dependent on buffalo milk.

In most countries containing sizable buffalo populations the scientific principles of breeding have not been put to any serious test so far. Currently, no country has an effective breeding program for buffaloes, although in many places selective breeding could be accomplished more readily with buffaloes than with cattle since there are numerous large herds already on government farms with better management than village cattle receive and established record keeping. At present much more attention is being directed to cattle. Clearly, the future of the buffalo depends upon the emphasis of the various countries. If they choose to build new strains of cattle based on crossbreds of improved breeds, the buffalo's role is very likely to become small. However, emphasis on systems of breeding and management for buffaloes seems justified.

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VII

HANDLING OF MILK AND MEAT PRODUCTS IN THE WARM CLIMATES

17

E. J. SIEGENTHALER

Milk Handling and Processing in the Warm Climates

A realistic approach to handling food in a technically young country, usually under adverse climatic and other conditions, requires considerable adaptation to the usual way of thinking in the temporate zones. In the latter, society requires that everything used in the daily diet meet stringent standards. Even a glass of water drawn from a faucet must be approved by a certifying agency as to its physical, chemical and bacteriological quality. The same standards apply to food items stocked on the shelves of a supermarket. In addition, nearly all foods are within the financial means of most all the population. This cannot be the yardstick used to judge and evaluate food handling in areas of food scarcity and low incomes.

The Food and Agriculture Organization of the United Nations presents some striking calculations to demonstrate the magnitude of the needs for milk and milk products. If, for example, man, woman, and child in the countries of the N–S 30° latitudes were to have only one-fourth liter of milk per day, then every day for the next ten years one new plant capable of processing 100,000 liters daily would have to commence operation (Pedersen, 1966). Thus every deciliter of milk produced for human consumption is important.

In the temperate zones foods must meet stringent standards But where food supplies are short, people usually eat whatever food is available, even if it is unsafe, because of satiety and it increases their chances of survival For this reason it is suggested that all means of making use of milk, including milk of low quality, be explored It is beyond the scope of this chapter to develop scientific methodologies or broad technological aspects for milk processing A review by Rice (1965) covers a number of these points in an excellent fashion It also contains an extensive bibliography on some aspects of processing milk and milk products The main purpose here is to indicate some of the measures that may be utilized to make better use of the milk supplies that are available or can be provided in many areas of the warm climates

All methods of technology should be utilized to improve food and make it safer, but due respect should be paid to the given conditions in the environment, including the people The first step in improving the quality of foods is to orient the attitude of the people to change Without their support, both as producers and consumers the quality of milk products will become poorer rather than improve

During the last 20 years many projects have shown that a dairy industry is technically and economically sound even under adverse climatic conditions The Bombay Milk Scheme is an excellent example (Khurody, 1962) Before planning and establishing a dairy industry, however, it is essential to make surveys of the area On this subject a great deal of background material can be found in publications by Whyte (1967) and Whyte and Mathur (1968), as well as in the monograph Milk Hygiene (1962) published jointly under the auspices of FAO and WHO Information is needed on the number of producing animals in the area, the amount of milk which may be currently available, including that produced and marketed in small lots (Figure 17 1), along with projections for later stages of developing milk processing plants and market outlets and the existing means of transportation, the physical elements of the environment that may limit the production of milk in the area (Chapter 2), and the quality and amount of water, as well as its temperature during different seasons FAO and a number of dairy supply companies have prepared questionnaires for such surveys covering everything from quality of milk, and availability of electrical current and fuel, to import restrictions and the organization and financing of a plant A compilation of such background material will determine the type of the plant fluid milk, cheese and butter, or concentrated products like evaporated milk or milk powder The establishment of large processing units is generally not warranted in the initial stages of development. Slower

FIGURE 17.1
Two Indian girls in Guatemala buy milk from a village farmer and transport it to a distant market place for resale.

development raises less difficulties. Furthermore, until the project is firmly established, its management should remain the responsibility of advisors with experience in the processing of milk under similar conditions. The local staff can then be trained during the gradual improvements in their own environment until they are ready to take over the entire scheme.

MILK FOR FLUID CONSUMPTION

When launching plans for dairy development, it should be kept in mind that the highest possible return to both producer and processor is obtained when the milk is used for liquid consumption. Even heavy imports of dairy products do not change this general rule. There is one notable exception: if the local population is not in the habit of drink-

FIGURE 17 2
Nomadic tribal peoples of southern Asia frequently use goat skins as containers for milk. The skin bags are suspended so the neck portion can be used for withdrawal to the churning bag (Courtesy E J Siegenthaler)

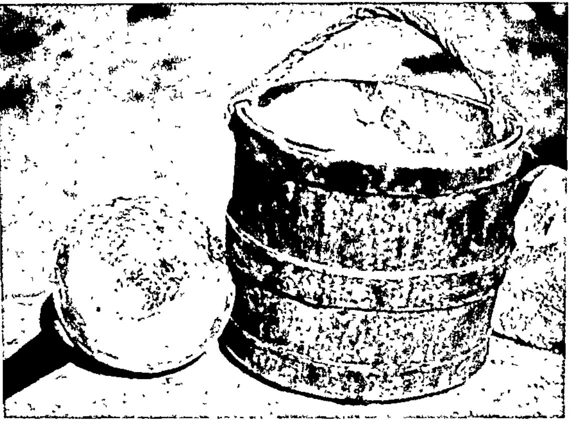

FIGURE 17.3
In rural villages and nomadic tribes milking pails and ladles are often made of wood with hand tools. (Courtesy E. J. Siegenthaler).

ing fresh milk, as in certain areas of the Andes in Latin America, the manufacture of a white cheese will make the valuable milk solids available for consumption in another more palatable form.

A fundamental requirement in handling milk and milk products is cleanliness of utensils. Under field conditions this is not easily accomplished. Goat skins (Figure 17.2), calabashes and locally made containers of wood (Figure 17.3) and other materials are still widely used. The sanitation of these receptacles is to say the least, rather doubtful. In this light, the use of old oil drums and kerosene containers properly cleaned is a step forward. Another unfortunate but common practice is the placing of a block of wood or bundle of straw on top of the milk in an open container to minimize slopping and loss when transported over long distances. In many instances such a practice has been employed for generations without anybody objecting. Changing such customs is not always easy; it must be done diplomatically to avoid offending the local population as illustrated in Figure 17.4 and 17.5.

Another problem that must be coped with is the adulteration of milk before the establishment and enforcement of dairy and food legislation it can be expected that up to 90% of the milk sold on the

FIGURE 17 4
Herdsmen in the Himalayas agreed to replace their wooden buckets for transport of milk to a small cheese factory with cans loaned to them This was the first step in improving the hygiene conditions of the milk and made it possible to convert it into cheese (Courtesy E J Siegenthaler)

local market will contain added water Numerous vendors operating side by side, sell milk for different prices It is no secret that the amount paid is in direct relation to the added water What makes it even worse is that the adulteration is done by people often lacking the most elementary knowledge of hygiene Lukewarm water from dirty containers standing for hours in dusty, smoky huts is frequently used for this purpose The writer witnessed a milk handler ladling water from the paddy field into milk buckets Because adulteration often provides additional income the producer and the perambulating salesman of raw milk generally such as the Dudhia of India, object to ceasing their trade and taking the milk to a plant or collecting center The present price is probably higher than the plant could be reasonably expected to offer Obviously an organized dairy scheme cannot afford to purchase and sell milk without guaranteeing a standard composition and quality Producer incentives in the form of a graduated price structure has served to reduce adulteration of fluid milk One successful scheme is illustrated in Figure 17 6

The development of a dairy scheme depends a great deal upon the number of producers that can be reached and trained simul

FIGURE 17.5
Hygenic conditions for handling milk in East Africa were improved by demonstrating to the local women that it was more pleasant to transport the milk on their heads to collection points in closed topped cans than in open pails. (Courtesy FAO).

taneously. This is one of the reasons that at the very beginning the milk should be collected from all the farmers who will release their milk, regardless of its quality. Milk that is not taken in during the early stages reaches distribution channels by other avenues, thus spoiling the market and making the customer suspicious. Milk that does not meet the standard established for fluid consumption can be used for manufacturing dairy products. If it is of very poor quality, it can be converted into butter oil (ghee) and casein.

The producer's price must be determined by the hygienic conditions of the milk, and possible adulterations with water. To detect the degree of adulteration with reasonable accuracy may prove difficult, however. In order to estimate the amount of added water, the fat percentage and the specific gravity of the suspicious sample should be determined. This part can be accomplished with ease, but to make it useful, one must know the fat percentage and the specific gravity of unadulterated milk of the same origin. Because there are so many factors affecting the composition of milk—e.g., irregular feed supply, manner of milking, suckling calf at the beginning or end of milking, use of milk of different breeds or admixture of other milks (buffalo,

FIGURE 17 6
Reduction in adulteration of milk and improvement of hygienic conditions can be brought about by checking for adulteration before several producers and paying a premium on the spot for good quality milk (Courtesy W Schulthess, FAO)

goat, ewe) and interval between milkings—valid estimates of fat content are difficult to obtain. Moreover, the elaborate formulas by which the solids-not-fat and the addition of water are calculated work fine under known and more or less standardized conditions but are hardly reliable in the environment described above. It can hardly be expected that in this environment a cryoscope and a trained technician will be available to determine the freezing point of milk.

In spite of these drawbacks, a fairly efficient system of milk payment can be established by using fat determination as the main test. Base price is paid for what appears to be unadulterated milk. For all milk of lower grade, less butterfat, rigorous deductions are made—deductions that make the addition of water economically uninteresting. Suppliers delivering above-average quality obtain a bonus. The butterfat is analyzed in composite samples. At every delivery an aliquot amount of milk is transferred to a jar containing a preservative (potassium bichromate, formalin, or benzoic acid). The milk is tested about twice a month. As conditions allow or call for, additional tests (reduction time and sediment) can be introduced. This procedure has a definite educational value. At a later stage it can be replaced by a more accurate one. If, at the beginning, it is difficult to set a base price acceptable to all parties concerned, concessions can be made. In general, a policy of slow progress raises the least difficulties.

Guérault (1964) claimed that milk produced under tropical conditions showed an increased bacteriostatic action. This apparently occurs in spite of a multiplicity of contaminating agents such as dust, flies, insects, and unclean containers. It would probably facilitate dairy development in the tropics if this observation could be substantiated by scientific data. However, Auclair (1968) compared 137 samples of cows' milk from four tropical countries and 40 samples of buffalo milk from India to 164 samples of cows' milk from French dairies and concluded that fresh milk of cows and buffaloes from tropical countries did not differ in bacteriostatic properties from cows' milk from temperate zones.

In the early stages of dairy development refrigeration may not be available. If uncooled milk has to be transported over long distances, the use of a preservative should be carefully evaluated. Hydrogen peroxide is an inexpensive, non-toxic, and easily removable preservative that has been approved for use by an expert panel of FAO. The Food and Drug Administration of the U.S. has also sanctioned the treatment of milk with hydrogen peroxide for production of various types of cheese. This process is currently used by makers of Swiss cheese in Wisconsin. The possibilities and limitations of its applica-

TABLE 17.1
Equivalent quantities of hydrogen peroxide

Calculated as pure H_2O_2 %	mg/liter = ppm	Milliliter of hydrogen peroxide/Liter of milk: 30% solution = 98.9 vol	35% solution = 115.3 vol	39.5% solution = 130.1 vol
0.02	200	0.6	0.5	0.45
0.04	400	1.2	1.0	0.90
0.06	600	1.8	1.5	1.33
0.08	800	2.4	2.0	1.80

tion in facilitating milk collection under tropical conditions were investigated by Siegenthaler (1967).

The recommended procedure is that the preservative be added to the milk as early as possible. It is immaterial whether the milk is still warm or has been cooled. First, all extraneous matter introduced into the milk during milking and handling must be thoroughly removed as such particulate matter harbors and protects microorganisms—in other words, decreases the bactericidal efficiency of the preserving agent. Metal filters equipped with single-service cotton pads are best. If these are not available clean cloths can be used, but they require special treatment. After each use they must be thoroughly washed, sanitized by boiling in water for at least 5 minutes, and then dried in an area protected from dust. The quantity of hydrogen peroxide to be applied should not exceed 0.8%, calculated as 100% H_2O_2. Table 17.1 shows equivalent quantities of the commercial hydrogen peroxide concentrations usually available. The amount needed to obtain a desired concentration in the milk can be read directly from the table.

The required amount of hydrogen peroxide is mixed with five times its volume of cold water and is then well stirred into the milk. Provided milk so treated has at the outset a methylene blue reduction time of not less than 1–2 hours, it can be efficiently preserved with 0.08% H_2O_2 for 24 to 36 hours under usual ambient tropical temperature (Siegenthaler, 1967). If, before pasteurization, preservative is still detectable, a trace of catalase (maximum 1.5 ml/100 H_2O_2) diluted with ten times its volume of cold water will decompose it into water and oxygen. Residual hydrogen peroxide can easily be detected by means of Miles Peroxide Detection Sticks. The paper strip is dipped into the milk and immediately removed. If no color change is noted within 30 seconds, the peroxide has been destroyed. A blue-green color indicat[illegible] hundred p[illegible] of peroxide. These sticks are packed one [illegible]vailable from the Miles Chemical Company, Ell[illegible]

THE MILK PLANT

A pasteurizing and bottling unit calls for a costly plant and experienced personnel. But the establishment of a fairly modest unit can serve as a pilot project for later development. As local milk production builds up, the plant can progress at a comparable pace and the personnel can become progressively more competent in operating complicated equipment.

In well developed plants, continuous flow pasteurizers have almost completely replaced the heat treatment by the holding method for pasteurization. However, the High-Temperature Short-Time units, or plate pasteurizers, with all their delicate gadgets and controls are anything but foolproof. They require expert attention during the entire operation. Moreover, in an area where the availability of spare parts presents a problem, a breakdown might well mean the shutdown of the entire pasteurization plant. On the other hand, the vat, tank, or batch type of pasteurizer is, from the constructional viewpoint, rather simple. It consists of a jacketed vat with an agitator. The outside is covered with insulating material. The milk is heated by hot water or steam passing into the space in the jacket. Under continuous agitation the milk is heated to 63°C where it is held for 30 minutes. After draining the hot water, the jacket is filled with the cooling medium, which is first cold tap water and then ice water.

One important feature of the vat pasteurizer is its flexibility. Its operation can be continued throughout the day and it can serve as a holding tank. If required, additional or larger units can be installed with a minimum of costs and construction changes. For detailed information the reader is referred to one of the following: FAO/WHO (1962), *Milk Hygiene*, or *Milk Pasteurization*, (Hall and Trout 1968).

Packaging of the milk after it is pasteurized requires careful consideration. It is impossible to discuss the relative advantages of glass bottles and single-service cartons here. In the transition period—before the establishment of the dairy development project—a simple procedure is probably best. To large customers (hospitals, schools, army camps), the milk could be delivered in sealed cans. The retail customer could buy a bottle and bring it to the distribution center for filling from a dispenser. This has hazards due to varying concepts about sanitation of the bottle. A more practical approach would be to have facilities to provide a sanitizing rinse to the bottle before they are filled. In Israel good results have been obtained by packaging pasteurized milk in single-service plastic sachets (half liter polyethylene bags) for distribution (Rosenfeld, 1968).

Milk prices are largely determined by volume of sales. If prices are high, dairy development will be restricted. Toning of milk can be

a solution to this problem Toned milk is obtained by standardizing high fat milk with nonfat dry milk and water This process makes it possible to increase considerably the output of market milk and at the same time hold down prices to consumers If the sale of fresh milk cannot be made attractive to the general population, the manufacture of derived products is even more likely to fail

FERMENTED MILK

If raw milk is kept over an extended period at ambient temperature it turns sour This is because lactic acid producing bacteria are practically always found in raw milk If the milk is of low quality, and there is likeliness of pathogens being present, the milk should be boiled or pasteurized Such heat treatments destroy not only the undesired organisms but the lactic acid bacteria as well After boiling or pasteurization, the lactic acid producing bacteria (starter organisms) must be added in the form of a culture or starter to produce sour or fermented milk The culture is very often nothing more than sour milk from a preceding batch Sometimes lactic acid culture is also added to raw milk to speed up the souring or fermentation In other words, soured milk, fermented milk, and cultured milk are synonymous, in all three the milk sugar is converted into lactic acid, which brings about coagulation

In many areas of the world more milk is consumed in a fermented form (Figure 17 7) than as a fluid product Yoghurt, Kefir, *matzoon*, and *kumiss* are soured milks consumed in southeastern Europe In the Middle East and a number of Arabian countries the equivalent product is *leban* On the Indian subcontinent almost two-thirds of the milk produced is converted into *dahi* and in Spanish speaking countries fermented milk is distributed as *'leche agria "* An enumeration of sour milks the world over would be a mere list of words in foreign languages denoting more or less the same product.

The spontaneous souring of milk without an appropriate heat treatment and without the use of a bacteria culture cannot be relied upon to control all pathogenic organisms The dairy technician or sanitarian is aware that spontaneously soured milk is not a hundred percent safe However, a technician at an outpost faces many problems and has to make many decisions that are often hard to evaluate by a supervisor back home who is not familiar with the conditions in a country For example, is it permissible during a limited transition period to accept, and maybe even promote, spontaneously fermented milk products, taking for granted that the indigenous people undergo

FIGURE 17.7
Dahi, a fermented milk product, is popular all over India. It is made, transported, and sold in "single service" pottery bowls, which are also made by the farmers. (Courtesy E. J. Siegenthaler).

a better natural immunization than those living in countries with enforced food protection laws? Or must the technician slow down the development of a project by accepting and passing only perfect food? Have not many of the local practices, in spite of their limitations, proved their worth throughout generations? The best answer to the questions boils down to which is the lesser of two evils. The decision must be reached by the advisor at the local scene. In judging the validity of decisions among localities one must bear in mind that it is much easier to plan on paper or to direct technical assistance from abroad than to implement the plans in the field.

There are books and manuals available describing the manufacturing of fermented milks step by step. But most of the recommended procedures require equipment and utensils as well as special bacteria cultures often unavailable in remote areas. The following procedure takes into account village conditions and combines the art and tradition with the knowledge of controlled manufacture of cultured milks in dairy countries.

The milk is run through a filter to remove all extraneous matter and then brought to a boil. It is cooled to ambient temperature by placing the vessel in 25–40°C water. When the milk reaches the desired temperature range, it is inoculated with about 5 percent of the previous day's sour milk and kept warm until it is clotted and has the desired acidity. This will take between 3 and 10 hours. There are a number of factors affecting the time of fermentation. In a well

equipped dairy plant everything can be kept under control the percentage of starter, the activity of the starter, the incubation temperature, and the milk that is converted into the cultured product All these factors can be adapted to each other in such a way that the milk shows the desired acidity after a preset time interval Under village conditions this is impossible More often than not, even thermometers are not available and the incubation temperature "slides" from high to low, therefore, fermentation can proceed rapidly or slowly Once the milk reaches the desired acidity, as measured by taste, it should be cooled If cooling is not possible, the acid production progresses further, the coagulum becomes firmer and firmer, and finally separation of whey will occur Except for a more sour taste, the product is perfectly all right for consumption If facilities for cooling the fermented milk are available, the product has a longer shelf life

The handling of starters (bacteria cultures) requires a few additional remarks Temperature within the range of 20 to 40°C promotes the growth and production of lactic acid, which in turn is responsible for clotting the milk Any sour milk, regardless of its local name, can be used to function as a starter If the milk looks gassy, tastes unclean, or is otherwise not very palatable, the following cleansing process helps in most instances No laboratory is required but a thermometer is indispensable Approximately half a liter of the sour milk is heated under continuous stirring until it reaches 62°C and is subsequently cooled to ambient temperature This exposure to heat kills practically all coliforms and most of the pathogens but a portion of the lactic acid bacteria survive this procedure During this heat treatment the liquid part separates from clotted protein Some of the greenish liquid (whey) should be mixed with an equal amount of boiled milk and then kept protected from insects and dust for 24 to 36 hours at a temperature around 30°C During this period the surviving lactic acid bacteria start growing again, turning the milk-whey mixture sour This mixture can be used as a starter in place of the sour milk previously described

CHEESE

Cheese as a Fermented Product

The origin of cheesemaking dates back several thousand years The area of origin appears to be an Arabian country Pouches made from sheep and goat skin as well as the true stomach (abomasum) of young

ruminants have served to the present time as receptacles for milk. According to the legend, sometime in the dark history a herdsman kept some milk in a pouch of a domesticated animal; the milk curdling enzyme, rennet, in the skin of the stomach lining caused coagulation. This chemical process is still the fundamental process in making traditional cheeses. The other basic process, alone or in combination with the milk curdling enzyme, is the lactic acid fermentation. Whether the milk is coagulated by rennet or by acid makes no difference as both processes cause the curd to shrink and thus promote drainage of whey. The expulsion of moisture to the desired level is controlled by cutting the curdled milk and applying heat. The basic difference between sour milk and fresh cheese is merely one of moisture content. Salt, low acidity, and in certain varieties of cheese low moisture content, are the preserving agents.

Distinctive varieties of cheese have been the result of manufacturing cheese from milk of different mammals, in different localities, and under different climatic conditions. And in more modern times new types have been developed by altering bacteria cultures and manufacturing steps. Inducing and guiding the fermentation on a pathway to a natural and appetizing product became an art long before the basics of microbiology were known (Figure 17.8). In many societies, the art of cheesemaking has been handed down from father to son for centuries. The science of cheesemaking, on the other hand, is less than a hundred years old. Research elucidated the basic steps—curdling the milk, shrinking the coagulum, pressing, salting, and ripening the cheese—but did not change them. With the application of scientific knowledge in modern factories, defects in the cheese can be avoided and products can be standardized.

Currently the cheesemaker is able to convert milk of moderate or even low quality into a product that is palatable and safe for consumption. In a modern dairy plant with all the sophisticated equipment, the milk can be freed from pathogens, reduced in bacterial count, and deodorized if necessary. The cheese can be cured in moisture and temperature controlled rooms until it is ready for consumption. There are no technical problems in operating such a factory successfully under the most adverse conditions, although there may be economic problems. If unlimited funds are available, it is easy to find someone to launch the project.

To guarantee continued success, however, a developing scheme should be economically sound. If the project is financially attractive for the participants and self-supporting at an early stage, cooperation is more readily obtained. Thus a modest unit or pilot plant for later

FIGURE 17 8
Zsirpi the cheese of the Himalayas is made from sour buttermilk The curd is squeezed through the fingers forming a kind of noodle which is dried in the sun (Courtesy E J S egenthaler)

expansion may have a better chance of survival initially than a big plant A modest beginning also permits expansion of the program and training of the indigenous personnel in the skills required for large operations Starting with a small operation does not mean making ir responsible concessions in quality The product produced must be safe for human consumption whatever equipment and facilities are employed since it is impossible to keep milk entirely free from con tamination by microorganisms carried on the dust particles found in and on dairy utensils The large percentage of these are likely in nocuous but there is always the probability of pathogens entering the milk as well For this reason either the milk or the cheese should undergo a heat treatment similar to pasteurization

In the traditional cheesemaking process bacteria cultures are indispensable Transferring bacteria cultures daily to a fresh medium and keeping such cultures active over long periods are very difficult without an incubator and some form of refrigeration In addition cheeses are with few exceptions products of a fermentation which means that temperature control in the curing and storing facilities is indispensable

Cheese as a Non-fermented Product

In many situations the requisites for cheesemaking described are not available. This need not deter the manufacture of cheese as a certain type, white cheese, can be made without fermentation and bacteria cultures. This type of cheese is made in many different parts of the world. In Latin America it is called *queso blanca*. The equipment requirements are small (Figures 17.9 and 17.10); in fact, utensils available in almost any kitchen are suitable. It can also be manufactured on an industrial scale. Some heating of the milk is required however. In general, rennet is the coagulating agent but acid can be used. The latter agent is somewhat more difficult to make and has other drawbacks which will be described later. The milk can come from any source—cows, goats, ewes, camels, llamas, or yaks. Of course, the fat content of the initial product will influence the flavor. As white cheese is not a ripened (fermented) product, it can be consumed fresh or can be pickled for storage.

Rennet is the most important ingredient in the making of white cheese. Rennet is sold in the form of tablets, pastes, and liquids. Tablets are most widely used and are the most practical in a cottage industry. Very recently rennet substitutes, which also serve the purpose, have reached the market. Every manufacturer supplies exact information on how to use his product for cheesemaking. The rennets of different sources do not deviate much from each other. Most of these coagulating agents (enzymes) show a strength of about 1:100,000; that is, one part of the agent coagulates 100,000 parts of milk at a temperature of 32°C in one-half hour.

The required amount of rennet is dissolved in one part water to 100 parts milk. The rennet solution is then well mixed into the milk that has been brought to between 32 and 35°C. After coagulation has taken place (30 to 45 minutes), the curd is broken up with a fork or harp-like stirrer. The resulting particles should have a diameter of not more than one centimeter. The curd-whey mixture is kept in motion by gentle stirring for another half hour. During this time the particles increase in firmness. At this stage the cheese is ready for the heat treatment. This has a twofold purpose: (1) the destruction of pathogens that might be in the milk, and (2) the further contraction of the curd particles with the resulting whey expulsion. The temperature of the mixture is raised in not less than half an hour to 65°C under continuous stirring. After the mixture reaches this temperature, the whey is drained. The easiest way to collect the cheese is by running curd and whey through a muslin bag. If the cheese is made for con-

FIGURE 17 9
The Nomadic tribes of the Middle East use few utensils for cheese making The freshly drawn sheep s milk is brought to coagulation with a rennet tablet The curd is ladled into a muslin bag from which excess whey is forced (Courtesy E J Siegenthaler)

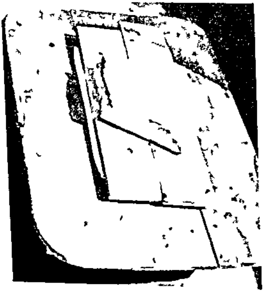

FIGURE 17 10
Excess whey may be pressed from the curd by placing the bag containing the curd between two boards and applying pressure with a stone (Courtesy E J Siegenthaler)

sumption within a few days a uniform distribution of salt is desirable This is accomplished by mixing 0 5 to 1% of salt by weight—calculated on the volume of milk used—into the crumbly mass This can be done on a flat surface or in a bowl of appropriate size Fifteen minutes after adding the salt, the accumulated whey is expelled The curd is then spread about 5 centimeters thick on cloth and placed on a slightly tilted board for a better runoff of the residual whey The sides of the cloth are folded over to form a flat package The package is pressed between boards with sufficient pressure to force the cheese curd into a continuous mass The recommended pressure for pressing is about five times the weight of the cheese Three to five hours later

the cheese cake can be unwrapped and cut into squares of the desired size.

If the white, unripened cheese is not consumed within a few days, preservation is necessary. This type of cheese has a high content of lactose, which makes it particularly susceptible to spoilage. There is only one way to preserve it when modern facilities are unavailable. The cheese squares are placed in a wire basket and immersed for a few seconds in 85°C water containing 10% salt. Thus treated, the chunks can be kept in glass jars or earthenware containers under saturated (22%) salt water for many months. These containers can be stored at ambient temperature but transparent jars should be kept in a dark room. Obviously the pickled cheese has a high salt content. By soaking it in fresh, clean water for 12 or more hours—depending on the size of the pieces—enough salt is removed that even children will find the cheese palatable.

As mentioned earlier, organic acids can be used in place of rennet in the manufacture of white cheese. Those most frequently used are natural lemon and lime juices, for such products as Italian Mascherpone cheese. A steady supply of food grade organic acids might often be a problem in certain areas, particularly if there are currency restrictions on importations and there are no local sources.

A more detailed description of the principles of cheesemaking in the tropics, including detailed information on the application of the hydrogen peroxide treatment of milk for cheesemaking, is given by Siegenthaler (1968).

BUTTER AND GHEE

There is good reason to believe that separating the creamy fraction from the milk dates back to the time when milk from animals began to be used for human food. It is also conceivable that the first butter was churned accidentally when milk was carried in a skin pouch on a pack animal. The churning process has undergone many changes in the course of time—from the use of skin bag (Figure 17.11), querling in vessels (Figure 17.12), and shaking receptacles with and without dashers, to the use of elaborate churns and continuous buttermaking equipment. Although a great deal of milk fat is consumed in the warm climate areas, more of it is burned in worship and religious rituals than is consumed. Fortunately, fat malnutrition is not as evident as are diseases resulting from lack of protein.

In the absence of equipment for centrifugal separation, gravity creaming provides the only available means of obtaining cream for

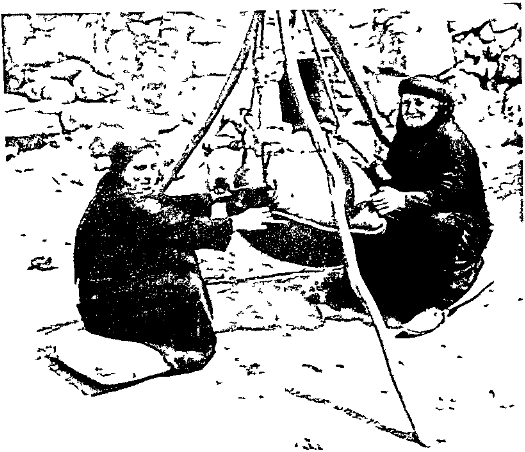

FIGURE 17 11
Butter is often made by Nomadic tribes by churning in bags made from animal skins (Courtesy E J Siegenthaler)

churning The cream is skimmed off after about 12 hours of standing in a shallow pan The milk underneath, or residual product, is often converted into a local variety of cheese or, in households, the whole milk is churned and the remaining buttermilk used for cheesemaking In the warmer regions milk curdles before a substantial cream layer is formed This is most likely the reason for churning sour milk, as done with *dahi* for the preparation of ghee on the Indian subcontinent.

Butter made from sour cream and butter made from sweet cream (or milk) are still the two main classes of this product The former has a fuller flavor, particularly when cultured cream is used, but a shorter shelf life Sweet cream butter, on the other hand, is less subject to defects such as rancidity and other objectionable taints Addition of 1–2% salt covers slight taints and extends the shelf life However salting is not practiced in all areas because of preferential tastes

FIGURE 17.12
In northern India tribesmen may use wooden barrels to churn. Agitation by a wooden paddle rotated through alternating pulls on a leather strap. (Courtesy E. J. Siegenthaler).

Butter made from spontaneous soured cream is not recommended for fresh consumption. In modern factories such cream can be neutralized, pasteurized, deodorized, cultured, and then converted into an acceptable product. Such facilities are usually not available in the early stages of dairy development. However, the butterfat of low quality milk or cream can still be salvaged for human consumption by converting it into ghee.

As a rule it is better to prevent the occurrence of cream defects than to try to correct them afterwards. Smoky flavored milk, cream, and butter—widely encountered under primitive conditions—can easily be avoided by keeping these products away from open fires. Smoke imparts an undesired flavor. Furthermore, such particulate matter, as well as soot and dirt, serves as a carrier of microorganisms. Cream with a pronounced weed flavor or that with cowy, gassy, moldy, or other strong off-odors can be considerably improved by washing. This is accomplished by mixing 50% fresh, clean water into the cream and reseparating it. The containers used in handling milk should be glass, earthenware, or alloys of zinc or iron. Milk, cream, and butter should not ordinarily be allowed to stand in copper and its alloys (brass and bronze) since they may induce flavor and aroma defects. Contamination with decaying wood and polluted or stagnant

water is often responsible for rancidity Heating to a temperature of 75 to 80°C prevents this as well as many other defects The physical condition of the butterfat during churning is important. Butterfat solidifies only if the cream is kept for several hours at low temperatures, i e , close to 10°C, which is also the best churning temperature This procedure avoids excessive fat loss in the buttermilk, regulates the final moisture content in butter, and ensures a good body and texture If possible, preference should be given to the churning of sweet cream

Filling the churn more than half full invariably prolongs the churning time and may even prevent butter formation altogether The churning process takes, under ideal conditions, 30 to 45 minutes, depending on a number of factors When the butter granules are 3 to 4 millimeters in diameter, the butter is washed by draining off the buttermilk and adding an equal amount of water After a few more rotations of the churn this water is removed Additional washings are recommended with off flavored cream, but with every washing some of the desired butter flavor is removed as well The final step is then squeezing and pressing the butter until it becomes a homogeneous mass In modern equipment this is done inside the churn In many countries and where only small amounts are to be worked, "kneading is still done by hand Air and water pockets in butter not properly worked are potential nuclei of spoilage

Churning of milk, even in a small scale operation, is uneconomical and impractical in many respects There are numerous types and makes of inexpensive manually operated milk centrifuges available, which make the separation of milk and cream an easy task On the other hand, making butter with equipment developed locally does not represent a real problem as long as it is possible to clean it properly

The process of washing and reseparating cream with off flavor and off tastes has been mentioned, but prevention of such defects is better than correction This can be accomplished by preserving the cream with hydrogen peroxide Successful experiments in the use of this product were conducted in India by Nambudripad *et al* (1952) The procedure is the same as with milk, mentioned earlier

The shelf life of butterfat can be prolonged by further removing the moisture Butter oil, clarified butter, ghee, and semneh denote the same product with only minor local differences To evaporate the water, the butter is heated to about 120°C When the temperature reaches the boiling point of water, strong foaming takes place, which makes the use of oversized pans indispensable After evaporation of all the moisture, which requires 3 to 4 hours, the protein and some lactose are slightly charred and settle out. This reaction imparts the

flavor component for which ghee and semneh are known and liked. After partial cooling the butter oil may be poured into smaller containers.

DRY MILK PRODUCTS

From the standpoints of utility, convenience, and maximum consumption, it might be advantageous for countries to concentrate on condenseries and milk powder plants rather than plants for handling fluid milk. Where refrigeration is not available, or expensive, milk with a long shelf life at ambient temperature is highly desirable. People working for wages are usually paid at weekly or other intervals. Most of the buying for the household is done soon after pay is received. If a weekly supply of milk could be purchased at one time, it is likely that milk consumption would be higher.

Unfortunately the provision of milk supplies as dry powder or canned condensed milk is not feasible because of the high volume required for an efficient plant. Nelson (1954) showed that full utilization of machinery and labor could not be obtained with volumes of less than 30,000 liters of fluid milk per day. Because of the amount of heat energy required to remove the water, the cost of the end-product is high in comparison to that of local fluid raw milk. The high cost of processing usually results in a lower price paid to producers than for milk sold as fluid milk. Hence, the establishment of centers to produce low moisture products is unattractive to producers and governments except perhaps as an aid in storing milk supplies.

OTHER MILK PRODUCTS

Currently considerable thought is being given to the promotion of sterile milk and sterile-flavored milk drinks, ice cream, and any frozen product with a milk base to stimulate consumption of milk products. It seems that settling out of some of the constituents, coarse or flaky texture, or slightly atypical flavor are acceptable as long as the product is cold or frozen. The psychology is that people of all income levels seem willing to spend money for cold drinks. Oftentimes cheese or other milk products will be partially or completely rejected by poorly fed people, but few refuse cold, sweetened products. Furthermore, there are no serious technical problems to enriching milk drinks or desserts with other proteins.

Although the potential for chilled milk products may be high for

nounced. Gradually all parties concerned will gain experience and further steps can then be taken in due course.

But most important of all, *education must precede legislation.* A health inspector visiting farms and taking milk samples for evaluating quality should not stress law enforcement and fines, but should be concerned with constructive help. He should try his utmost to assist dairy farmers and milk vendors to improve conditions and come forward with constructive suggestions and recommendations. The backbone of progress and success in any development scheme is collaboration and cooperation with the indigenous people, and this requires also an understanding of their problems.

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18

J. R. STOUFFER

Meat Handling in the Warm Climates

The need for high quality animal protein for human consumption is universal. More animals are probably needed to provide the minimum daily allowance of animal protein recommended by FAO (20 grams); but a greater quantity of animal protein could be made available from existing animal stocks if careful attention were given to all aspects of meat handling. The preceding chapters dealt with the problems of animal health, nutrition, and breeding in the warm climates. This chapter is concerned with some of the fundamental considerations in producing large quantities of good quality meat and by-products from animals.

The handling of meat and by-products is an important part of any livestock development plan. In many countries of the temperate zone, investigations are constantly being conducted to determine the most appropriate and economical methods for handling meat; hence, procedures are constantly changing. Due to numerous limiting factors in the N-S 30° latitudes, such as suitable technology, resistant cultural habits, lack of capital for developing facilities, and unreliable supplies of stock, not much has been done thus far in establishing meat processing industries in much of the region. International organizations, e.g., FAO, WHO, and UNESCO, have done a great deal to create

awareness of the value of meat and meat products prepared under hygienic conditions And the International Bank for Reconstruction and Development has lent support by providing loans for the construction of abattoirs to upgrade the meat products But much more remains to be accomplished K V L Kesteven, formerly of FAO Animal Production and Health Division stated, "If we had the means for satisfactorily providing hygienic milk and meat our goal of 20 grams of animal protein for nearly all people could easily be attained by the mid 1970's This would not only enhance human health but would represent the greatest stimulus to animal producers by providing needed incentives for efficient animal production " (FAO, 1968) The case may be overstated, but the points are well taken, adequate processing of animal products is extremely important to both producers and consumers

CHARACTERISTICS OF MEAT

Any living organism is a complex functioning system of processes which work together to support the organism When an organism stops living, nature causes most of the systems to degrade or break down the formerly living organism so that all of the nutrients are available for other forms of life As we examine the preparation of meat for human consumption, we ought to be aware that following slaughter there are chemical, enzymatic, and physical degradations or breakdowns of the carcass and its components that take place almost immediately Several of these changes are beneficial for the production of palatable and tempting products, while others result in degradation defined as spoilage

Only in recent years have the mechanisms of degradation and spoilage been clearly defined Even in well equipped units for handling both fresh and preserved meat products, the problems associated with degradation have not been completely solved The economic losses resulting from inability to control all factors leading to spoilage have been staggering Because temperature is an important factor in spoilage, it is readily apparent that degradation will be even more difficult to prevent in the warmer regions

The animal is normally bled after stunning This brings about an immediate change in the systems within the animal The lack of oxygen available to the tissues results in the formation of lactic acid as an end product of the conversion of the glycogen in the tissues The pH of living tissue is neutral, but the buildup of lactic acid shifts it to

the acid side. The rise in acidity and the use of energy involved bring about the condition known as rigor mortis. The onset of rigor mortis occurs 2 to 4 hours after slaughter. This is the period of least tenderness in the carcass; tenderness will improve gradually with aging through autolysis.

Autolysis is the process whereby enzymes and chemical reactions break down the protein structure in connective tissues and muscles to produce a more tender and palatable meat. In the U.S. it is common practice to hold meat under refrigeration at 1°C for 10 to 20 days to allow autolysis to take place. Aging at this temperature controls the rate of autolysis and minimizes the danger of spoilage. Some autolysis occurs at 10°C or higher but generally actions of microorganisms proceed so rapidly that spoilage occurs before tenderness is improved. Aging darkens the color of the meat. Dark colored meat is acceptable in countries like the U.S., but it is not marketable in most tropical areas because of the association of the color with spoilage. Besides, the expensive facilities needed for aging add to overhead costs for a meat industry.

Another important factor is the microbiological characteristics of meat. Meat is highly susceptible to invasion by microorganisms. External contamination is a constant possibility from the moment of bleeding until consumption. Most microorganisms that thrive on meat produce discoloration and undesirable odors and flavor. It is fortunate that meat does not support pathogenic microorganisms under ordinary conditions.

The points made about changes in meat following slaughter apply most appropriately to carcasses of cattle, but pork, lamb, poultry, and fish are also susceptible to rapid deterioration unless placed under low temperatures.

Since the formation of lactic acid in the muscle tissue depends upon the level of glycogen in the tissues before slaughter, antemortem handling of animals is important to meat quality. Rough handling of an animal or placing it under any stress prior to slaughter lowers the glycogen level. The below average glycogen in the excited animal leads to a delayed onset of rigor mortis. Moreover, the meat darkens in color very rapidly and it has poor keeping qualities because acidity is rather high (pH 6.5–7.0). Recognition of the influence of antemortem animal treatment on the quality of meat is not new. The pirate Dan DeFoe recorded in his diary in 1720 that cattle that his raiding party hunted and fatigued would not keep even when salted.

Clearly, meat is a highly perishable product that requires careful handling at all stages. Where ambient temperatures are warm to hot, sanitation conditions are primitive, facilities for keeping animals

before slaughter are poor or non-existent and a means for chilling the carcasses immediately after slaughter is lacking, major problems in providing good quality meat arise

SLAUGHTER FACILITIES

Before sites are planned and established for slaughter facilities, surveys ought to be made to determine such things as size, availability of animals, water supplies, and conditions of the meat that will be accepted in the projected market If the market does not accept chilled meat, for example, cold storage facilities will not be practical Planning for processing meat is discussed at length by Mann (1962, 1963), as well as by Albertsen *et al* (1967) and Burdette and Abbott (1965)

As recommended in Chapter 17 for milk plants, the establishment of large processing units is not generally warranted in the initial stages of development A policy of progress by stages raises least difficulties Development of the plant in stages has the disadvantages of taking longer to reach a high level of efficiency and overall cost of installations and equipment, but these are outweighed by the advantages of getting started sooner with a lower cost outlay and having time for training sufficient personnel

A clean place to slaughter is important for the production of meat with good keeping qualities and for the most efficient utilization of the animal and its by-products Whether the slaughtering place is a simple slab or a large abattoir, it should offer facilities for humane slaughter and efficient meat handling Whether meat handling facilities are extensive or unsophisticated the two basic considerations are to keep the meat clean and to remove as much of the animal heat as possible

Oftentimes slaughtering takes place in remote rural areas This is likely to occur where there is a small village and a limited number of stock available for slaughter There are few if any, facilities set aside specifically for the slaughter process The minimum facilities should include a slab or hard surface floor that can be flushed and kept clean It is also advisable to have a method for hoisting the carcass during slaughter This makes possible a more thorough job of bleeding and aids in the physical handling of the carcass during slaughter Where a hoist or gantry hoist is not available, the hide or skin of the animal is ordinarily used as a dry area for dressing of the animal When the animal is felled for bleeding it is kept on its back and as the hide is removed it is spread out in order to protect the carcass from dirty areas around the dressing operation Care should be taken to mini-

FIGURE 18.1
Slaughter slab established near a small village in northern Nigeria for hygenic slaughtering. The slab provides a means of collecting blood and reducing contamination of hide and viscera. (Courtesy J. K. Loosli, Cornell University).

mize contaminating the hide as its value can be greatly reduced through negligence. It is important to have water available for flushing the area and keeping the operator and the carcasses clean. Mann (1963) provides very explicit guidelines on construction and needs for both simple and complex facilities.

Figure 18.1 illustrates a satisfactory slaughter slab in a rural area of Nigeria. The lack of much direct light in the photograph indicates that the slaughtering is being done in the early morning hours in order to take advantage of the cooler temperature and to get the carcass into the market for sale the same day.

The basic difference between the slaughter slab and the small slaughterhouse is that the latter has a roof and is enclosed on all sides to improve control of insects and human traffic that is not directly engaged with the slaughtering (Mann, 1963).

A public hall for slaughtering is often available in larger popu-

lation centers Such a house would probably contain all of the basic requirements for slaughter pens and some additional refinements. The most important consideration is that the facilities be kept clean and properly maintained for subsequent use of different individuals and for various species of livestock More frequently, complete modern slaughter accommodations, including refrigeration, are being constructed in areas of large slaughter operations in many parts of the tropics These are operated in much the same way as plants in the temperate regions Such facilities minimize problems during slaughter, and refrigeration aids in quality However, the extensive investment cannot always be justified on an economic basis

Where water is scarce or unsafe, the best meat can be turned out by "dry slaughter" The slaughter area must be clean and dry when the operation starts A hoist is necessary, otherwise, dangers of contamination will be high The animal is worked on hanging from the hind leg on the hoist for bleeding, most of the skinning, and splitting After stunning, sheep and goats may be worked from a hoisted position Without water available special care must be exercised during evisceration to avoid puncture of intestines, gall bladder, or urinary bladder

Slaughter is much easier with water available Large quantities of water are needed for animals awaiting slaughter, for flushing the carcass, for cleaning edible parts—e g , the intestines—and cleaning hides or skins, and for general sanitation It is, of course, desirable to have ample supplies of clean hot and cold water under pressure throughout the slaughterhouse, but this is frequently not practical A major problem of providing water is obtaining the equipment needed to bring it from a satisfactory source to the killing floor For a source to be satisfactory, it must supply potable water If only contaminated water is available, dry slaughter is recommended, followed by cleaning of equipment with water that has been heated and then allowing the slab and equipment to dry in the sun between each day's kill Rain water is ideal and every effort should be made to collect it and store it for the slaughter operation The use of sea water is not recommended as it imparts a fishy" taste to meat

Dry slaughter may be used for swine In this process the hair is removed by singeing (Figure 18 2), followed by scraping the skin with a knife The "wet method" is more universally practiced Although the hair may be removed by wetting and scraping, as shown in Figure 18 3, scalding to loosen the hair is recommended This means that where pigs are to be slaughtered, there should be included a tank large enough for submerging at least half the pig at one time Provision must also be made for either direct heating of the water

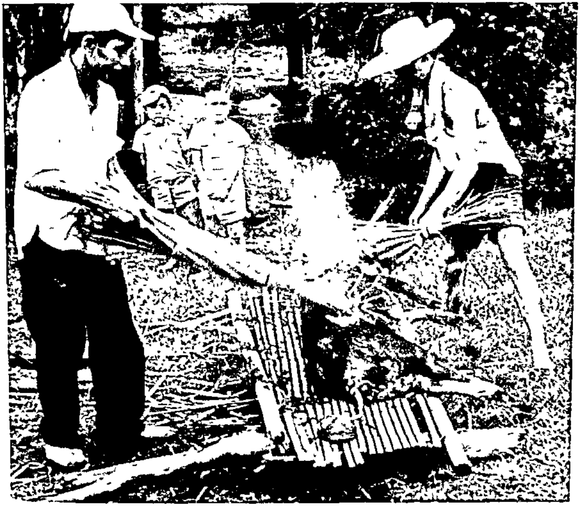

FIGURE 18.2
After the pig has been killed and bled, it is common practice in rural areas of the Philippines to remove the hair by singeing, followed by scraping. (Courtesy J. K. Loosli, Cornell University).

in the tank or piping it to the scalding tank from elsewhere. (A pig ought to be submerged in water 60–62°C for 3 to 6 minutes to loosen the hair.)

In many countries poultry are slaughtered principally on the farm, where sanitation standards are ordinarily low. Antemortem care, cleanliness, proper bleeding, and handling of poultry is as important as for livestock; therefore, in planning slaughter facilities provision should be made for poultry. A small room with a door leading to the outside is desirable, instead of a corner of the slaughterhouse, is recommended because considerable struggling takes place, which leads to contamination of the slaughterhouse, equipment, and livestock carcasses nearby.

All accommodations for slaughter, irrespective of size, must be functional, simple, durable, reasonable in cost, and capable of expansion without interfering with operations. Where the standards of butchers and meat handlers are low, structures and equipment need

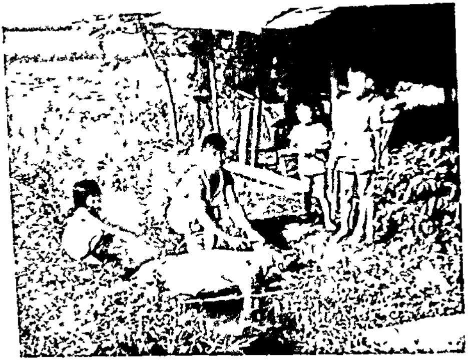

FIGURE 18 3
Hair may be removed from a pig by continuous wetting and scraping with a knife although this requires more effort and time than scalding (Courtesy J K. Loosli Cornell University)

to be simple in order that workers may be able to use them without having to acquire skills beyond their capacity With respect to planning facilities, cultural and religious practices should also be borne in mind (Mann, 1963) For instance, in Moslem countries, slaughtering of swine may not be permitted on the same premises as slaughtering of other species Islamic law requires that animals killed for food should be slaughtered so that the blood flows out completely This means a hoist of some sort would be mandatory

Mobile field abattoirs have been tried in Kenya and elsewhere for use where livestock are widely scattered and in areas distant from markets It has also been recommended that mobile units would make the harvest of game animals more practical Success has been limited because the areas they would best serve are a long distance from markets, which means the field units need to incorporate processing facilities for canning or drying But this makes them too cumbersome for adequate mobility Fresh meat could be moved out by air but this is usually at a higher cost than can be tolerated The Kenya Veterinary Department has found that construction of low cost sta-

tionary field abattoirs in various locations is more practical. Operation time is rotated in order that supervisory personnel and inspectors can oversee a number of these.

MEAT HANDLING REGULATIONS

For protection of both producer and consumer, slaughtering should be regulated. It is generally recommended that slaughtering facilities not be privately owned, especially where there is not a high regard for sanitation. Public control permits designation of location, as well as an opportunity to control sanitation. If public ownership is properly exercised, it has numerous advantages, including (1) insurance that a slaughterhouse is located a reasonable distance from human habitation; (2) regulation of water supplies and disposal of offal; (3) permits services to livestockmen at low cost to attract them to slaughterhouses; (4) assurance of humane treatment of animals before and during the killing process; and (5) serve as a partial means of providing a more uniform flow of meat to markets.

If publicly owned slaughterhouses cannot be provided, an organized system of licensing is necessary for adequate control of slaughtering. Licensing is usually managed by local or central government authorities who issue licenses for premises, butchers, and other workers. If the premises or applicants are found to be unsatisfactory, the original licenses may be withdrawn or renewal licenses refused. It should be made a legal offense to utilize a place for slaughtering animals of any kind unless minimum requirements for sanitation are recognized with an official license. Similarly, licenses issued to butchers and other workers should be voided if unhygienic or illegal practices occur. The best practices are to have licenses effective for not more than a year and renewals made only after a certification by a qualified authority that sanitary conditions are satisfactory. Of course, to insure compliance, health authorities should make unannounced visits to slaughter premises and the public should be continuously advised to purchase meat only from approved operations.

For purposes of meat inspection, it is desirable that hours of slaughter be regulated in order that ante- and postmortem examinations can be carried out by a responsible inspector (Albertsen *et al.*, 1967). The responsibility for meat inspection lies with the local authorities or with a branch of the central government. Preferably codes should be designed to suit the community, taking into account food preferences and religious customs. Inspection should be progres-

sively intensified as circumstances warrant If regulations are too restrictive at the outset, problems of enforcement may defeat any progress being attained Nonetheless, certain standards should accompany the opening of any new slaughterhouse

Normally meat inspection covers not only the routine examination of internal organs, lymph nodes, and muscle tissue, but also inspection of the sanitary state of the slaughterhouse and staff and the disposal of waste The instruction of butchers and handlers of meat in hygiene is frequently among the duties of the inspector

Regulation of slaughtering assists too in animal production If records are kept of origin of livestock, suspected disease problems can be traced and control measures exercised more readily than in unregulated situations

Concurrently with the establishment of new facilities and regulations, vigorous publicity campaigns must be waged within the area The attitude of the local people determines the success of meat handling regulations Would-be consumers should be encouraged to buy only products produced at the new unit, otherwise, "black marketing" will undermine the whole program Local authorities can also render valuable assistance in assembling animals—resting and feeding animals for several days or more represents an example

PRESLAUGHTER HANDLING OF ANIMALS

Plans for construction of slaughterhouses and their operation ought to include provisions for humane slaughtering According to Mann (1963), humane slaughtering is no more expensive than methods involving some degree of cruelty Proper procedures should begin when the animal enters the slaughterhouse area From the moment the animal enters the area until it is bled, it should not be allowed to suffer from heat stress, fatigue, or abuse, and should be kept apart from carcasses or offal

Drinking water ought to be available in the "holding yard" as animals deprived of water lose weight rapidly, thirsty animals become restless, and adequate watering keeps feces wet, which helps remove much of the intestinal contents before slaughter The hide is more difficult to remove from animals that have been deprived of water Animals should be fasted for 12–16 hours before slaughter to reduce the amount of undigested food and feces in the intestines Fasting also improves the quality of the meat and reduces risks of contamination of the carcass by puncture during evisceration Resting

animals in a "holding yard" allows them to become accustomed to their surroundings, which in turn reduces excitement.

If some animals are to be held more than 24 hours, a second holding pen is needed as those waiting more than 24 hours should have light feeding. This is more important for pigs than ruminants. If pigs are deprived of feed and water for more than 24 hours they may be unsuitable for the production of sausages or ham (Mann, 1962).

From the holding yard or pen, the animal should move through a chute narrow enough to prevent turning around. This should feed into a stunning pen. A stunning pen is recommended. It may be about 2.25 meters in length and 1 meter wide. Here the animal is rendered unconscious before being bled. A knocking hammer can be used for stunning by an operator standing above the pen. However, unless the operator is experienced, a captive bolt pistol is recommended for best humane slaughter although its initial cost is higher. A captive bolt pistol is placed against the animal's forehead by an operator standing above the pen or behind an opening. When the pistol is fired, the animal is stunned by a steel bolt piercing the skull and damaging the brain.

If a stunning pen is not possible, a ring emplaced in the floor of the slaughterhouse may be used to secure the animal's head, and thus insure accuracy of the blow for stunning. The ring ought to be located where the animal does not see carcasses and where the floor is not slippery.

Cruelty in the slaughter of pigs, sheep, goats, and calves can be prevented by the use of a special stunning pen separated from the sticking and bleeding pen. Stunning may be carried out with the same hammer or pistol used for cattle, but the use of electricity for stunning these species has become the recommended practice. Electricity is applied with a pair of tongs. For pigs, the tongs are applied immediately below the ears for 6–10 seconds with a current of 60–70 volts. The time and voltage is similar for calves and sheep but the tongs are applied between the eye and the ear (Mann, 1963).

The requisites for satisfactory stunning are (1) quick rendering of unconsciousness without abuse or mutilation; and (2) the prolongation of unconsciousness until the animal has bled out. Death should come instantaneously and without visible preparation to the animal. Cruelty may arise due to ignorance of animal behavior. Sticking a knife into the altanto-occipital space causes motor paralysis, but does not destroy the senses; hence, the animal is still fully conscious even though unable to move. Spearing a beast, as practiced in areas of Africa, is cruel and dangerous, and results in bruises on the carcass, meat with poor keeping quality, and renders the hide almost useless.

Like other species, poultry must be carefully handled before slaughter They need to be rested in a cool place and have access to water, but no food for at least 12 hours Late feeding prevents good bleeding and makes the intestines tear easily during evisceration

SLAUGHTERING

A part of humane slaughter is to bleed the animal out as rapidly as possible after stunning Following stunning, the animal should be shackled, hoisted to a bleeding rail and bled Sticking is done with a knife about 16 cm long very shortly after stunning The sooner, the better, as the rate of the heart beat and blood pressure are high immediately after stunning thereby assisting bleeding Cattle are best bled in the hoisted position after cutting the hide under the throat where the vena cava, jugular veins, and carotid arteries are situated Sheep and goats are stuck behind the jaw just below the ear, but for pigs, an incision is made approximately 5 cm above the breastbone on the front of the neck and the knife thrust toward the entrance to the chest, cutting the carotid arteries and jugular veins

Skinning, or scalding in the case of swine, follows bleeding, then comes removal of the viscera Unless the carcass is to be moved to market as a whole unit, it is split down the spine while hanging, then washed, trimmed, and inspected Excellent guidelines on step-by-step recommended slaughtering steps for cattle, sheep, goats, pigs, and poultry are given by Mann (1963)

Often the offal, comprised of tripe, guts, blood, and feet, is considered the "fifth quarter" The offal is usually sold for consumption, although it is sometimes used in lieu of wages to workers If the offal is to be consumed, its cleaning, processing, and inspection for diseased parts should receive as close attention in preparation as the carcass

Even though cutting off the head with a knife or ax is widely practiced for killing poultry, it is not recommended for slaughterhouses The preferred method is stunning with a blow on the back of the head with a hard object or holding the head with the thumb and forefinger to force the mouth open After the blow or forced opening of the mouth, a sticking knife is inserted into the mouth with the sharp edge downward and pressing toward the base of the skull In this way the veins can be severed

Feathers can be plucked by either wet or dry methods For wet plucking a small scalding tank with water at about 54°C is needed Scalding time is about 30 seconds If dry plucking is used, the nerve

center controlling the feather muscles must be destroyed. This may be done by inserting a sticking knife into the cleft in the roof of the mouth toward the brain and on reaching the hind brain the knife is turned left and right.

It is recommended that poultry be hung up for bleeding and a bleeding cup used to aid in cleanliness and to avoid bruising, which occurs if the bird is allowed to thrash about on the floor.

CARCASSES AND BY-PRODUCTS

The carcass of a slaughtered animal is that portion of the major skeletal muscle mass which is associated with the skeleton as separated from the offal and by-products during the slaughter operation. After completion of the dressing operation the carcass should be cooled insofar as possible. Chilling soon after slaughter greatly enhances its keeping quality. It is desirable that the carcass be kept at around 1°C until it is ready to be broken down into smaller cuts for distribution. If the market will accept "aged meat," the carcass will be ready to market 7–10 days post mortem. Unless the carcass has a fair amount of external fat, there is little to be gained from keeping the carcass under refrigeration beyond one week after slaughter.

Even though the meat may be consumed within 24 hours after slaughter, lowering the internal carcass temperature is important. Where refrigeration is not available, slaughtering late in the evening or before 7:00 A.M. is recommended to take advantage of the cooler night temperature to remove some of the heat from the carcass. In determining the safe slaughter-consumption time, it should be kept in mind that a safe keeping period between temperatures of 5 and 10°C is no more than 3 to 4 days. If the carcass temperature exceeds 10°C the safe keeping period is no more than 36 to 48 hours. When carcass temperature is scarcely lowered below body temperature, keeping time is less than 36 hours (Albertsen *et al.*, 1967); therefore, it is necessary to sell the day of slaughter. There will be considerable sacrifice in tenderness of meat handled in this way but nutritive value will not be impaired.

Meat from bulls has the longest keeping quality and pork the shortest, with that of steers, cows, calves, sheep, and goats intermediate. Meat from healthy animals will keep longer than meat from diseased ones. Meat from bruised or improperly bled animals and that contaminated by feces during evisceration or by dirt from the hide tends to have a shorter safe time than noncontaminated meat.

An intact carcass is less liable to damage by microorganisms than

one that has been cut up A dry external surface prevents the multiplication of microorganisms, thus if the carcass is not to be chilled, quick drying prolongs its keeping

If the edible portions of the offal are properly cleaned, their keeping quality is approximately the same as for the carcass

Hides and skins represent important by products if properly treated There are a few basic factors that contribute to the value of the hides An injury to the live animal can damage the hide Flaying or skinning requires skill to prevent cuts, which lessen the value Poor bleeding leaves blood in the hide, thereby reducing keeping quality The hide should be thoroughly fleshed and dried as early as possible to prevent deterioration The animal heat should be allowed to escape before salt is applied (Aten, *et al* , 1966)

It is possible to air dry hides by hanging them in the air in a warm dry area Hides should not be placed on the ground for drying because enough moisture will be trapped underneath to lower keeping quality In humid areas, drying of hides is accomplished by sprinkling salt on the flesh surface Salt should be applied at the rate of one unit of salt to an equivalent weight of hide (FAO, 1966) If the volume of hides is large, it is possible to use a pickling process, in which the salt is put into solution This requires equipment to keep the hides moving in order to get adequate penetration of the salt Sometimes it is advantageous to remove the hair by a flaking or liming process before pickling This will depend upon the ultimate use of the hide The main point to keep in mind is that hides and skins have properties similar to those of meat, hence the same careful consideration needs to be given them to insure maximum yield

Fresh killed poultry needs quick chilling to preserve quality If refrigeration is not available, chilling may be accomplished by immersion in cold water Following chilling the carcass should be thoroughly dried as soon as possible Preparation of poultry depends on market demand For some markets only the feathers are removed, while other require poultry that is partly dressed (only intestines removed) or fully dressed for cooking (eviscerated and head and feet removed) Undrawn carcasses tend to keep better than fully dressed ones unless the latter are frozen

In all species, irrespective of condition at the time of slaughter, there is an accumulation of fat on the external and internal surfaces of the carcass Some markets will accept the fat associated with the cut of the meat. In others, such as in Iran and Iraq, the fatty tissue will sell for more than the lean But in many markets excess fatty tissue is rejected Especially for the latter markets, fat becomes an important by product of meat preparation In order for the fat to be

useful, it must be separated from the fatty tissue. The process is generally referred to as rendering. Fat is ordinarily rendered in processing plants by one of three methods—open kettle rendering, steam rendering, or dry rendering.

Space will not permit description of handling fat. Suffice it to say that incorporation of means for processing fatty tissues into the slaughterhouse should be carefully considered since the salvage of fat reduces problems of waste disposal as well as helping to make the most efficient utilization of the entire animal. Since fat decomposes rapidly, particularly under warm temperatures, it should be handled as carefully as the lean meat and offal; otherwise, the resulting product will have little or no value. Recommendations on equipment and processing of fat and fat products are described by Mann (1963) and several of the other references.

PRESERVATION OF MEAT

The four processes in widest use for preservation of meat are (1) drying (including smoking), (2) curing, (3) canning, and (4) refrigeration. More recently attention has been given to use of radiation and microbial inhibitors—e.g., carbon dioxide and antibiotics. Drying and curing were probably practiced before recorded history, but chilling and heating came along much later.

Drying

The World War II era saw the beginning of commercial dehydration of meat. Several types of driers have been used, such as cabinet or batch, tunnel, conveyor, rotary, and vacuum driers. All require sophisticated equipment and precision control of temperature and humidity. Today, both raw and cooked meat are prepared for storage by one of these methods, but air drying continues as a practice in remote areas. Drying is the cheapest and most effective method of preservation.

Biltong is the common name for dried meat in South Africa (Mittendorf and Wilson, 1961). The process of making biltong is simple, and therefore it affords a good means of preserving meat in excess of consumption requirements when refrigeration is not available. Weather conditions are important in the preparation of biltong; meat can be dried only during hot weather. In a humid climate success will not always be attained as mold and mildew may cause such dete-

rioration before drying is completed that the product will spoil or be unpalatable Ante and postmortem care is essential for the production of biltong with high keeping qualities The carcass should be hung to cool before being cut up In cutting up the carcass, the aim is to produce long strips of muscles of near equal thickness Care should be taken to cut the muscles lengthwise The best thickness of the strips is no more than 1 0 to 2 5 cm^2 After cutting, the strips are rubbed with salt on all surfaces before hanging to dry or they may be covered with a layer of salt and left over night before hanging in the sun Hanging is ordinarily done with galvanized wire hooks suspended on a line between posts The time needed for drying depends upon the size of the strips and the weather conditions Kidneys, livers and lungs should not be dried, however, hearts and tongues dry well if cut thin and well salted Good biltong can be made with the least equipment of any processed meat

Charqui is a dry salted meat, which can be prepared using larger cuts and in more humid areas The meat is first preserved by salting and then by drying The fresh, unchilled raw meat is cut into chunks not more than 5 cm thick and weighing no more than 1 5 to 2 0 kg The pieces are hung on small "S" hooks in the shade for about an hour to cool, followed by submerging in a saturated salt solution for an hour Upon removal from the solution, the meat is laid on slats above the tank to drain The meat is then cured on a sloping platform where alternate layers of salt and meat are piled up to about 1 meter The following day, the pile is rotated top to bottom The process is repeated for 5 consecutive days with fresh salt used each time The best charqui is made by drying under shade rather than direct sun light Shade drying keeps the temperature low enough that the fat does not melt Charqui has good keeping qualities and is more resistant to infestation of beetles and attacks by molds than biltong, due to a higher residual fat content Whether to prepare biltong or charqui depends upon climatic conditions, type of meat available, availability of salt, and tastes The nutritional value of biltong is slightly superior as it has a higher protein content and more B vitamins In general, people accustomed to dried salt fish will prefer charqui, while those used to fresh meat accept biltong more readily (Mann, 1962)

Dried meat contains 3 25 times more protein than an equal weight of fresh meat If properly protected from insects and moisture, dried meat can be kept for one year or longer It has versatility in use After soaking in water, it resembles and can be treated as fresh meat It is even palatable raw Drying does not appreciably lower mineral content and most of the vitamins are retained

The disadvantages are that dried meat is subject to spoilage from exposure to air and light, which cause rancidity of the fat. High humidity or melting leads to decomposition; and attacks by insects are a continuous hazard.

Smoking

Smoking is a good means of meat preservation and adds flavoring. It can be done in combination with drying and curing or as a separate method. Smoking can be successful in either dry or humid conditions. The simplest method is to hang slices of meat over an open fire, but in general preparation of good smoked meat is somewhat more complicated. Keeping qualities are best achieved by a combination of curing and smoking. In large processing plants, smoking is scientifically controlled by partial cooking and adds flavor, principally for pork. Suggested plans for construction and operation of facilities for smoking are described by Mann (1963).

Canning

Canned meats are likewise an important commodity in many countries and should become more prevalent to insure best efficiency in distribution of meat. Heat sterilization (canning) is done by sealing the product in a container and then applying heat so that microorganisms are destroyed. Canning requires special equipment, well trained staff, and accurate control throughout the whole process. When properly done, it is the safest method of preservation. But the high cost of preparation will not make it practical for as full use of by-products as in the fresh state.

Satisfactory canning has a number of requirements: (1) the cans must be of high grade; (2) the can-closing machine must be maintained in accurate adjustment; (3) the raw material must be of good quality; (4) careful control of heating is required; (5) the cans require proper cooling after heat treatment; and (6) routine laboratory checks are necessary for quality control.

Unless all these requirements can be met, canning should not be undertaken. It is not recommended for most rural conditions. Nevertheless, when the technical requirements can be met, it is a very satisfactory means of handling meat.

Curing

Curing is basically the preserving of meat by means of curing agents, such as salt, sugar, vinegar or all three Curing agents are harmless bacterial inhibitors in high concentration, which do not kill microorganisms but inhibit their multiplication by making water unavailable to them Curing also enriches flavor, enhances color, and improves tenderness In places where it is not possible to have refrigeration, a partial cure can be achieved to extend the commercial life of meat for a short time Curing can also be used as a preliminary treatment to meat prior to drying, dry salting, or smoking The highest temperature at which curing can be successfully done is approximately 10°C Probably the only way to cure meat in hot climates, without refrigeration, is to carry out curing and storage below ground level

Bengal saltpeter (KNO_3) or Chile saltpeter ($NaNO_3$) and spices are frequently added to the cures Saltpeter is a mild preservative but it mainly improves color, especially in pork Spices are mainly for flavor Vinegar also improves flavor and serves as a bacterial inhibitor

Curing may be done in several ways The term dry cure is applied when the ingredients are used in dry form and rubbed into the meat. Dry cures are of two types—shelf cure and box cure Shelf curing is used especially for pork hams It consists of rubbing the meat periodically with salt and keeping the hams on shelves in a cool room Box curing is carried out in water tight boxes It is used principally for curing pieces of pork and beef After being well rubbed with cure, the meat is packed tightly in a box and covered with wooden planks, which are pressed down with stones The pressure brings the fluid out of the meat and tends to produce a solution of its own

Curing can be speeded up by using pickles or brines, which are simply dry cures dissolved in water The pickle or brine cure has the advantage that the meat can be put into the solution without preliminary treatment. Still, bacon and hams are usually subjected to a preliminary injection of brine to minimize internal spoilage The curing process is completed when the curing materials have penetrated evenly to the center of the meat. The time required varies depending upon the thickness of the meat, type of cure, strength of brine, and temperature conditions For dry curing, the average penetration is 1 2 cm of thickness of meat per week Although dry curing takes longer, the keeping quality of the finished product is greater

Like drying, curing requires little equipment and can be carried out almost anywhere if minimum ambient temperature conditions are

met. Curing also has the advantage that meat infested with trichinae or cysticerci can be safely used for human consumption after proper curing.

Refrigeration

Mechanical refrigeration is used to store and improve quality of much of the world's meat supply. It has made possible a tremendous trade between countries and represents great economic significance to the export economies of New Zealand, Australia, and other areas.

Although the primary aim of refrigerating meat is protection against spoilage, refrigeration also serves as protection against other forms of meat deterioration, such as oxidation of fat and adverse changes in color of the superficial tissues; and as pointed out earlier, it provides a means of improving tenderness through aging.

In order to obtain rapid cooling and at the same time restrict loss of weight, it is necessary to have a large refrigeration capacity and a rapid and uniform flow of cold air flowing through the cooling room. This makes the costs of construction and operation prohibitively high, except for larger meat marketing centers.

Preservation of meat in frozen form has gained rapid acceptance in the U.S. but remains in little use in tropical areas except where meat is imported in this form. With the rapid expansion of urban centers in all countries, no doubt refrigeration for short time storage and freezing will become much more widely practiced. The availability of capital for facilities and suitable personnel or operators and the speed with which consumers will accept meat more than a few hours after killing will largely determine how rapidly refrigeration becomes accepted in the N-S 30° region. In some situations the use of microbial inhibitors or radiation may play a more important role than refrigeration; however, more technology is required.

In brief, it is important to remember in handling perishable animal products that the first concerns are cleanliness and a safe, healthful product until consumed. Through inauguration of improved handling procedures, it will be possible to more nearly optimize efficiency of meat production. However, changes will come slowly. Those from outside who contemplate assi[illegible]in changes should bear in mind that many of the operation[illegible]m simple and obvious in

temperate zones will be more difficult in tropical climates with unskilled labor Persons accustomed to an easy flow of slaughter operations, means of protecting meat from vectors, ample water, and trained personnel will find themselves in a hostile environment The arts of improvising equipment and facilities, training of personnel, and fitting improved techniques into existing local cultural and religious patterns will be important for success

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VIII

LIVESTOCK PROGRAMS

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Developing Livestock Programs

The previous chapters have dealt with some of the major problems of livestock production in the warm climates, together with possible applications of technology. The progress over the last two decades in the expansion of livestock industries has been slow—not only because of the problems outlined in the previous chapters, but also because of the failure on the part of those concerned with development of livestock programs to fully appreciate the significance of all the factors that must be considered in order to bring about progressive livestock industries. Seemingly training of personnel for planning of well rounded programs for livestock development has been overlooked by those going as technicians from the temperate zones and certainly it has been neglected in the university training programs in the U.S. and elsewhere for students from the warm climates. The ensuing discussion is intended to create an awareness of the value of planning various aspects of programs, the importance of planning in the successful application of improved technology, and the role of economics in organization of resources.

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CONSIDERATIONS IN PLANNING

General Considerations

The question of how to allocate resources to expand food supplies is a serious dilemma for many countries of the N-S 30° latitudes. Although animal agriculture has been given relatively high priority in many countries, plant agriculture has usually been given top priority, largely because it is the most rapid means for expanding food production. Where there are strong social and political pressures for food supplies, governments tend to channel their major resources—including those obtained from outside—into plant agriculture. This is especially true where government supported livestock programs have failed to yield the expected returns. Livestockmen have not always been as cost-return oriented as they should be in making improvements and have thus earned a poor reputation. Moreover, there has been more resistance to the use of innovations with animals than with plants, due to the greater emotional involvement with animals. Coupled with these factors are the pressures from those who feel that food needs can best be met by plants alone.

With the current tendency for governments to base their allocations on cost-return considerations, allocations for enlargement and improvement of the livestock industry may continue to lag. This trend can only be countered by careful planning and excellent rapport between those concerned with livestock production and those in government responsible in programing for overall country development. Any significant changes in livestock production on an area or country wide basis will, of course, require trained personnel, appropriate research programs, and considerable financial resources. But it will take time to build the infrastructure needed to provide adequately trained personnel and suitable technology. In the meantime, those concerned with improvement in livestock production must speed up progress by careful application of the principles that have already been reasonably well established—e.g., assessing the physical environment in relation to the feasibility of types of livestock enterprises, principles of animal breeding, methods of feed production, and procedures for maintaining animal health.

A plan must not only be technically plausible, but also economically feasible and acceptable from both social and political standpoints. Large, mechanized farms offer the best technical and economic possibilities for increasing both total agricultural production and the output of livestock products; yet they are often politically unpalatable because a few individuals will control most of the land. History re-

veals that this tends to lead to exploitation of a sizable segment of the population.

In some regions of Latin America, one solution might be to develop large farms in relatively inaccessible, thinly populated regions, while developing family-size farms on the better lands along the rivers, in mountain valleys, and near urban centers. At the same time, it should be kept in mind that land in the hot, humid tropics is not cheap and therefore ought to be utilized as fully as possible. Even though remote tracts can be purchased at low cost, clearing and providing the necessary infrastructure of roads, housing, and services, such as health and education, make the cost per unit of animal product very high.

Coupled with the general allocation of resources, including land, are other aspects of livestock development that demand careful attention in the planning process. These are delineated below, not necessarily in order of priority.

The Initial Changes

Livestock development could benefit from recent experiments in crop production: in many countries changes in methods of crop production have been brought about by providing an initial package of practices that increased production enough to attract the required initiative and investments of capital. In contrast, the usual projections for animal improvement through artificial insemination, recommendations for expanded use of crops for forage production, and "improved management" more frequently than not have rendered relatively small increases in returns over those of existing methods. An increase of 10 to 20% over the common experience for milk yield, wool clip, or growth rate often goes unrecognized, either because environmental fluctuations mask the improvement or because the increase constitutes such a small change in income. An analogy would be a cultivator who sells only 10% of what he produces, the remainder being kept for household use. If he obtained a 10% increase in production, this would only increase his real income by 1%. In contrast, a cultivator who sells 70% of his crop production realizes a 7% increase in income with 10% increase in crop yield. This is another reason favoring sizable, intensively managed enterprises to drastically increase livestock production.

Few will resist innovations that increase yields and income many times, as some innovations are doing in crop production. But the cost of the inputs required to obtain a 200% or better increase is too high

for most livestock enterprises in the warm climates—be they holdings of a few hectares, tribal ranges covering large areas of unimproved land, "commercial dairy enterprises" with less than 30% of their females of all ages in lactation, or beef herds with less than 50% of the females over 3 years of age weaning calves each year.

If, by some means, the initial stage of high boosts in outputs can be attained, the acceptance of innovations that increase productivity 10 to 20% assumes a different character. A 20% increase in the weight of a calf normally weaned at 180 kg or an increase in milk yield per lactation in a herd averaging 3000 kg will give much greater purchasing power for inputs and bring about much greater motivation for further efforts on the part of producers than similar percentage increases associated with the methods presently employed.

Defining Program Goals

A livestock development plan should clearly separate the goals of real growth—meaning the expansion of the total output of livestock products—from the goals of social development and political participation. The latter might involve providing AI services on a free to all farmers without regard to cost of supplying the services. If real growth is desired, the expected returns for each alternative proposal must be clearly delineated. The usual justification for livestock programs is the need for increased human supplies of animal protein for the undernourished and low income groups. But frequently programs have failed to achieve this objective, particularly with small farms.

Where past experiences have indicated little improvement in welfare or total output of milk or other products from small farms, careful consideration should be given the question of whether countries should devote their limited technically trained manpower to increasing animal products from small holdings in rural areas. Numerous case studies of programs suggest that high levels of inputs for small holdings may be unprofitable in terms of the investments and the support required—e.g., the necessary extension service and credit, etc.—or even for social reasons. Generally, small farmers sell practically all their livestock products for needs of capital, choice of expenditure, or as a means of exchange to obtain greater satisfaction. As long as the animal or its products will yield goods of greater realized value, they will be sold to buy larger quantities of food or to vary routine food habits. A household in a rural village can ill afford to slaughter a pig or a cow for home use, therefore, these are sold routinely. Except on religious or festive occasions, the major animal

products used in rural areas are eggs and milk, both of which have the limitations of wide seasonal fluctuations in supplies and competition from other choices.

Since supplies from small farms are limited and inconsistent and there are restrictions on capital available to these farms for expansion, it would seem logical to give little direct attention to this segment of farmers—especially when the main objective is the expansion of the production of total food for human consumption.

Another factor that should be considered is that technological innovations tend to be picked up more rapidly by farmers specializing in livestock production than by small farmers. This means that "real costs," e.g., the services required, are high for small farms. Also, it has been found that small livestock holders are dual acceptors, that is, they may accept an innovation without making the necessary changes in related practices. For example, almost any farmer will accept a European-native crossbred animal if he has seen these among his neighbors' stock, but he may refuse to cease tying the cow's rear legs during the milking process and milking without the calf present, which are disturbing to this type of animal. He is also unlikely to recognize that the new animal should have more feed to realize its potential for production. The result is that little benefit is derived from the new animal. Still another deterrent is that profit maximization may not be as important in a subsistence or barter economy as the maximization of security and survival; accordingly, the small farmer may be very reluctant to accept the risks and uncertainty associated with new technology.

All these factors lead to the conclusion that if the primary purpose is total food production, the basic emphasis should be directed to promoting commercial or semi-specialized to specialized enterprises for livestock production. Those favoring this approach hasten to point out that the small farmer would not be ignored entirely as he would receive some indirect advantages through the more specialized operations—e.g., the opportunity to get a better male for use with his own stock.

Equally strong arguments can be put forth for giving small farmer programs a great deal of attention. (1) This approach would reduce more rapidly the causes of social and political unrest. (2) The small farmer is oriented towards high labor inputs and usually has spare family labor; hence, he could serve a useful role in certain phases of the total production cycle, such as rearing young stock that could be passed along to specialized producers. (3) The small farmer must be guided to make maximum use of his resources for the benefit of total economic development. (4) Although the colonial stereotype was that

"lazy peasants" refuse to work for an income beyond that needed for subsistence requirements, there is ample evidence that small farmers are economically inclined. They utilize their available economic resources. Even though they may be operating at low absolute levels of production, they will optimize at the ceiling of their mobilizeable resources (Wharton, 1968).

It is clear that no standard policy can be adopted relative to participation of small farmers in livestock improvement programs. Whether they should or should not be incorporated must obviously be a defined goal. More will be said about planning for the small farm later in the chapter.

In programs intended for the more specialized enterprises, a high degree of flexibility is required in the modernization approaches for all aspects of production, including feed supplies, disease control methods, types of animals, and management practices. Seemingly, emphasis toward commercial enterprises must be viewed on one of two bases: (1) either development in progressive stages of expansion; or (2) the enterprises developed in a single stage. To illustrate: A farmer may undertake a grading up scheme for his native cattle or sheep by crossing to an improved breed. Since improved husbandry and larger amounts of inputs must be closely associated with the grading process, for it to be successful, planning must be done on a continuing basis. Alternatively, farmers may establish complete new units or modernize older ones in one step. Complete modernization is an almost universal approach in poultry and swine enterprises and has occurred to a lesser extent for dairying, but is rare in beef operations.

Producer Motivation

The acceptance of technology is the end product of program development. Often those directly concerned with research in the animal sciences and supporting livestock improvement programs have moments of despair because their recommendations are not accepted readily by intended recipients. The causes may be numerous.

A technical breakthrough may have occurred at a research station giving evidence that with adaptation a significant improvement in the output of animal products could be realized. Those concerned with increased production regard this as a potential source for realization of the goal, but despite their efforts farmers have not adopted the new technology. The [illegible] reasons for resistance to adoption tend to fall into three categories: (1) those related to the farmers them-

selves, (2) those related to the technological innovations, and (3) those external both to the farmers and the innovations. The latter may result from environmental factors.

It should be kept in mind that whereas the developer of the technology thinks in terms of projected returns, the would-be user thinks in terms of real returns. When a local type cow is crossed with a bull of an improved breed, the projected return is that a crossbred will be produced that is capable of yields 200% with a 95% probability; but the real returns may be less than 50% greater than those from the native cow with only a 75% probability. There are no major reasons why the real returns could not equal or be even higher than the projected returns. When these two distinctions in returns are joined, one readily sees the divergence which can take place when a new innovation is being promoted. If the promoter of the technology knew the farmer's farm as well as the farmer did, the real returns would be the same as the projected. Since those advocating the use of the new technology do not have the same picture, their respective realities diverge.

The projected returns can diverge from the real returns for a number of reasons. A livestockman who is an "early adopter" and who has never previously tried crossbreeding, but only seen it on another farm or experiment station, tends to add a significant discount factor to any estimate of performance derived from his immediate observable experience; whereas, the "late adopter," who lacks experience, either rejects the technology or accepts it without adequate examination in relation to his own skills and his resources for supporting it.

Lack of awareness among farmers of the true merits of the proposed innovation may be due to improper methods of presentation. If those who present the innovation do not understand the new managerial practices required well enough to explain them thoroughly and answer all questions, they will fail in implementation.

It is practically impossible to integrate all the variables involved in the failure of farmers to adopt recommended technology. Nevertheless, certain major reasons have been identified. (1) The farmers may not understand the new technology because information about it has not reached them. (2) The farmers may have heard about new methods but may have insufficient knowledge or skills to utilize them effectively, or even understand their potential. (3) The new practice may not be socially, culturally, or psychologically acceptable. Frequently case studies of the impact of a new program, such as dipping cattle to control ticks, indicate that it has not been adopted because it would upset too severely the established pattern of social, economic, or political organization. The importance of such forces certainly can not be ignored, particularly among small farmers or tribal

herders. (4) Very often the new recommended practice has not in fact been locally adopted or tested under conditions that closely approximate those faced by the farmer. (5) Probably the biggest single cause of resistance to change is the unprofitability of the program recommended, as seen by the farmer. In many cases, the new technology may be physically better but not necessarily economically better. (6) Frequently the new technology is embedded in a physical process, such as the application of fertilizer to pastures. Unless the fertilizer is readily available to the farmer in sufficient quantities at the time when he needs it, knowledge of its potential contribution to his feed supplies will not result in its adoption.

As indicated previously, small farmers are seemingly the most difficult to motivate. Explanations vary. Some analysts rely upon noneconomic explanations—e.g., the indigenous culture militated against the new practice or higher production would disrupt the traditional habits. Closer examination reveals that the economic advantage has often proved illusory because the landlord secured all the gain, the money-lenders consumed any additional returns with high interest rates, the government guaranteed price was not paid, or the cost structure made the innovation unprofitable. Still another factor that requires recognition in the motivation of small farmers is the value of their total efforts. Robinson Crusoe did not try to reach the absolute maximum of total physical production on his garden plot because his labor had value in other pursuits. This simple fact is all too frequently forgotten by those who want to bring about changes in the farmer's production methods. If the farmer is asked to plant an additional crop for forage, he must weigh its labor requirements against the requirements of the main crop. He is aware that much of the forage crop may be wasted because he has no storage facilities. As a result he looks upon the extra planting as a poor investment of his labors.

Farmers, large or small, may be attracted to invest when market prices are good, but may later become disillusioned when the balance between feed and product prices becomes unprofitable. A good illustration of the point comes from a district near New Delhi, India, where a governmental program was pushed to increase the supply of eggs for the city beginning in 1959. By 1962 there were a large number of both small and large producers. The market was favorable as feed cost averaged \$10.60 per 100 kg while eggs sold at \$2.76 per 100. By 1964 the project had expanded the demand for feed until it rose to \$14.00 per 100 kg while the market price for eggs dropped to \$2.50 per 100 due to oversupply in the winter season. Because of the shift in pricing many of the producers were driven out of business. This experience illustrates two fallacies in planning. (1) The planners

projected low feed costs, but these could remain low only as long as the supplies came from local sources; when the demand reached a point that feed had to be imported the prices rose precipitously. (2) There was inadequate attention given to handling of the marketing (Jaggi and Robertson, 1965).

It is abundantly clear that if producers are expected to invest in new innovations they must be assured of expected real returns for their products, which will allow them to use inputs, including labor, to an economic advantage. Of all the instances of neglect in past programs, probably the greatest has been the neglect of incentives. Therefore, the importance of appropriate planning for incentives cannot be stressed too much.

Needs for Government Involvement

Properly conceived livestock improvement programs may carry hard loans (from commercial banks) and thus be self-sustaining. But, in general, some degree of governmental assistance is required for livestock programs, in the form either of direct subsidies to producers or support of services, education, research, training, or marketing. At the very outset, all plans for livestock improvement ought to include a clear delineation of the support required along with projections on whether the program will eventually be self sustaining, except perhaps for certain services, or will require continuous direct subsidy. For instance, if the objective of implementing new innovations in animal husbandry is to expand production on a free market basis, the plan should include provisions for governmental assistance through extension services, guaranteed loans, aid in developing marketing facilities, and perhaps support for farm record keeping and the maintenance of seedstock farms or artificial insemination services.

Similar types of support may be needed if the intent is to develop or expand an export market with the added services of health inspection and sanitation control. In order to establish and maintain an export market, there may be requirements of direct subsidy for assembling and feeding out animals, and processing products (e.g., operating slaughterhouses).

If the projections are directed primarily toward increasing the supplies of animal products or maintaining livestock products within a fixed market price level, high levels of subsidy may be required either of a direct or indirect nature. In Puerto Rico, the government has chosen for several reasons to maintain certain minimum levels of pork, egg, milk, and beef production even though competition from

imported products has been high. As an incentive, producers are paid directly $25.00 (U.S.) for each male calf reared, if it attains a minimum body weight by 6 months of age. This has markedly reduced the number of calves sold at 1 or 2 days of age and encouraged the expansion of beef production by growing the animals out to 350 kg live weight. In Venezuela, the government pays the cost of transportation of fresh milk from near Maracaibo to Caracas, which is over 600 km away, in order to satisfy the needs for an urban market and to provide incentives for production.

Indirect subsidies may be provided in numerous ways. For example, subsidies may be made through the milk processors, as in the U.S., where price supports exist for butter and milk solids. Or the subsidies may be channelled through such activities as supporting feed mills, livestock markets, or processing plants of one type or another, either by direct operation or by providing partial operational costs. Assistance may also take the form of a protected market where tariffs and preferential treatment are provided certain segments of the livestock industry. Restrictions against importation of animals or, on the other hand, underwriting part of the cost of importing improved stocks, represent examples.

Where no organized livestock industry exists, a government may need to bear the cost of setting up and operating installations. The Indian government has purchased land, set up housing for laborers and facilities for milk processing and delivery, and supplied technical management in order to establish milk colonies near most of the large cities (Khurody, 1967). Other governments have established and supported the operational costs of large farms for the purpose of providing improved stock for general distribution.

If the objective is to promote development through establishing or assisting cooperatives, support from public resources is usually required in the form of extension services, guaranteed loans, veterinary services, and capital investments in equipment or buildings. In almost every country of the world, livestock development programs assume that the government will provide certain services and training through extension services or government supported universities, research installations, veterinary programs, transportation, and communications. These are real costs and should be incorporated into the plan, at least for those features that call for expanded or new services. Frequently, proposals for livestock improvement have failed to clarify the needs for public fund support and the time limits within which these needs must be met.

Furthermore, planners frequently fail to appreciate the full scope

of the services required, particularly in regards to resettlement schemes for land reform programs In Puerto Rico the government planned a program to utilize 20,000 hectares of hill land, some of it on slopes up to 40%, divided into approximately 8 hectare farm units, with highly fertilized improved strains of grasses serving as the feed supplies Three types of operations were planned dairy operations with young stock reared on other farms, enterprises devoted entirely to rearing dairy replacement heifers from 6 months of age to time of first calving, and farms devoted to grazing steers from about 180 kg to a market weight of 385 kg These were planned as family farms They were expected to return to each family a level of annual income at least 30% higher than the wages customarily received for harvesting sugar-cane by hand

The expectations for all units were based on high levels of managerial skills, but the intended participants were former agriculturists or laborers with little or no livestock experience The levels of skills required were such that if a heifer rearer lost several animals or a beef producer failed to get 0 6 kg gain per day he would have less income for his labors than he could receive for cutting cane on a seasonal basis (6 months work) Similarly, in a dairy enterprise, if the calving interval dropped from the projected 380 days to the average for commercial dairy herds on the island (430 days), income level would decline below the established minimum Obviously when starting with unskilled people programs must be supported with adequate extension personnel The ratio, at least for the first year, should be one well trained agent per five, and not more than eight, families The high ratio is needed because the new livestockmen must have the full attention of the agent at least one day per week in order to be properly guided in learning appropriate husbandry skills

On the island of Trinidad, a dairy production program was developed with "turn key" (complete, including family dwelling, milking shed, pastures, etc) 8–10 hectare farms with all the land in improved pastures The participants were former agriculturists who received some indoctrination before going to the new farms The firms were stocked with Holsteins imported as heifers The "failure rate" on these farms has been high, principally because of lack of provision for the necessary trained technicians to oversee the proper indoctrination of the operators Numerous other examples of equally obvious deficiencies in planning could be cited, but the central point is that the level of husbandry planned to make "new livestock" enterprises feasible has to be supported with adequate technical assistance

Defining the Purpose the Livestock Are To Serve

A careful classification of reasons for keeping livestock will also help in decision making on allocations and priorities. The keeping of livestock generally falls into one of five categories: (1) To supply markets with products that can be afforded by some or there is a demand stemming from cultural habits. In some societies there is a demand for pigs smaller than the size for most efficient production, or for live poultry, which require extra handling before being consumed. Units that produce these products may or may not be adjacent to urban centers. (2) Livestock are kept mainly for agricultural power but also supply edible by-products. (3) Livestock are kept to provide some returns from lands largely inaccessible to markets. These lands are ordinarily unprofitable for agricultural production other than that realized through cattle, sheep, horse, goat, or camel production. (4) Livestock serve as a "bank" or a means of providing reserve food in periods of shortages; they are used as a feature of family celebration; or they are the main source of food and fiber. This category encompasses two subgroups of livestock keepers: sedentary agriculturalists and nomadic or semi-nomadic people. The former keep a few animals to supplement agricultural production. (5) Livestock are kept to enhance total food supplies by making fuller use of land and by-products that would not otherwise contribute to human food supplies.

In category (1) the market is restricted in comparison to total needs because the cost of products is outside the routine food budget for most households. For this reason, attempts to build viable livestock programs principally on markets of this type entail greater than normal risks. Categories (2) and (4) at present contribute relatively small fractions of the total animal products available as food to urban centers, and it seems they will continue to do so with the advances of mechanization and shifting of agriculture. Therefore, where resources are restricted, investments in programs for these two categories seem questionable. In any case, there may be only a few changes from current practices that can make the output of livestock products a substantial feature of income. Certainly the feasibility of providing direct assistance would warrant consideration more from a socio-political standpoint than from the standpoint of increasing human food supplies. A further limitation is that the seasonal nature of products from these sources works to the disadvantage of the producer and consumer. Category (3) may be looked upon in the long run as a transitional stage; current enterprises will probably be replaced eventually

by other forms of agriculture or become semi-intensive to intensive livestock operations with improvements in transportation

Category (5) encompasses at least three major groupings (a) cattle or other species kept near urban centers to utilize the by-products of industry and food processing, (b) livestock that serves as a phase in the crop rotation cycle and for the utilization of rougher lands on larger farms, or (c) fattening and dairy enterprises that draw all their animals from small farms Category (5) entails fairly high investment costs per operation and rather sophisticated management techniques

Specialized livestock enterprises already exist near all large urban centers (5a), particularly swine, poultry, and dairy units The number and size of these are subject to expansion at least in proportion to the enlargement of the urban centers This grouping is likely to have a further dimension—namely, units for fattening or finishing sheep and cattle, with feed supplies consisting largely of by-products from industry and food processing

Category (5b) should afford an opportunity for the most marked expansion in many areas for all but the very smallest farms For example, in southeast Asian countries, where the production of new cereal grain varieties is rapidly expanding, experiences have shown that rotation of crops is required in order to obtain maximum benefits from the improved varieties The best solution seems to be about three years of cereal grain production followed by one to two years of forage production India is devoting a great deal of attention to this possibility In operations of this nature, livestock production should become a phase of the total agricultural production on farms where heretofore its role has been marginal to submarginal

With appropriate planning, organizational structure, and government subsidies, largely through services and capital for facilities, category (5c) affords a potential for marked expansion As already indicated, it is difficult to create incentive among small farmers when it entails intensification of traditional practices They have limitations in both land and feed supplies Where farm acreage is restricted and only mature or near mature animals have appreciable value at the market, the small farmer is relegated to a "static state," meaning he must sell only older animals If these are females he loses the potential for producing more stock At the same time he cannot rear young animals beyond the weaning stage without selling due to limitations on feed supplies from his own sources

If the small farmer could anticipate annual sales of young animals (at approximately weaning age), his economic incentives would be much better For this procedure to be effective, organization and as-

sistance will be required in assembly and transportation of the young animals into units for growing out. Likewise, assistance and organizational structure will often be needed to establish the enterprises and feed supplies to make the finishing units effective. Finishing units could also be the most feasible method for drawing more productivity from categories (2) and (3).

It must be appreciated that the categories are broad and lack complete distinction. Nevertheless, examining projected programs with respect to these classifications will aid materially in development of plans, especially where resources to support improvement programs are very restricted.

Immediate vs Long-range Returns

The production of animal products requires efficient functioning just like any other business where the returns to management are closely related to the level of inputs. Since most improvement programs entail progressive expansion in output of products and simultaneously seek to establish creditability, they usually project pushing for acceptance of inputs in two stages—first, inputs that will provide immediate returns for land and animals and next inputs associated with long-range development. Some examples of inputs associated with or entirely based on increased labor intensity, which would be expected to provide visible or measurable results in 1 day to 3 months in output per animal unit directly or indirectly through the land, are as follows:

Immediate returns:

Animal

Providing adequate water supply
Attention to females during parturition
Flushing females before breeding
Treatment for internal parasites
Dipping or spraying for control of external parasites
Use of shades or shelters
Increased level of feeding
Use of salt and mineral supplements

Land

Application of fertilizer
Weed control in pastures
Rotational grazing
Drainage
Contouring of land to restrict runoff

Some examples of inputs that would require a longer time lapse before measurable effects could be realized are as follows:

Long-range return inputs:

Animal

Adjustment of breeding season
Use of better sires
Storing of feed
Use of shades or shelters
Vaccination

Land

Pasture renovation or new seedings
Establishment and use of irrigation systems
Clearing of land
Drainage to avoid flooding

Obviously these lists overlap somewhat—e.g., in use of shelters. But most of the inputs in the "long-range" list require fairly large capital investments, either direct or in equipment and facilities.

Another way of classifying planned inputs would be with respect to the outlay of capital required—small or large. Small capital requirements refer essentially to intensification of management and labor. Examples include close attention to females at the time of parturition, an extra crop of feed per year, and a limited amount of stored feed supplies. Some of these can be accomplished to a degree by individuals no matter what the level of enterprise. Large capital outlay may be associated with providing artificial insemination services and importation of stock. Land tilling, seeding, irrigation, the use of harvesting equipment, heavy applications of fertilizer, fencing, irrigation equipment, facilities for handling stock, and numerous other innovations are examples of large capital outlay. Some of those items initially sorted under large capital requirements could eventually be considered in the category of small capital requirements, in terms of unit output of livestock product. A tractor, for example, represents a major capital investment, but consistent use would make its cost low in relation to an equivalent amount of hand labor. Thus, in determining the classification of animal production methods and in developing approaches to motivate farmers, the likely speed of return and the capital requirements should be given careful attention.

Cultural Inhibitors

In the past many livestock improvement programs have fallen short of their goals because of failure to recognize cultural inhibitors. There exists almost everywhere some cultural practice that inhibits obtain-

Economics

Those recommending change need to arm themselves with as much data as possible to convince farmers of the economic feasibility of projected practices. The "clincher" of the sell will be the attractiveness of the profit motive presented. There is, for instance, a level of milk production per animal at which the production of forages becomes economical and competitive with food and cash crops. This threshold is related to the price paid for milk and to the costs of production. The farmer should be informed of the costs of various levels of technological advancement, e.g., establishing and managing pastures as well as the relative economic merits of growing and feeding green or stored roughages versus purchasing concentrates. Similar projections should be available regarding interest on investment in livestock, costs of maintaining livestock—other than feed costs—construction costs for facilities, and the many incidental costs, such as veterinary and drug costs, that arise with improvements in technology.

Tables 19.1–19.3 show the changes that can be expected in farmer investments and returns with employment of various levels of technology in beef producing enterprises. Table 19.1 depicts the expected changes in herd makeup, number of marketable animals, and gross income from a 1200 hectare enterprise from intensification of labor and some other adjustments that would increase the annual calving percentage from 35 to 50%. Obviously with a calving rate of 35% per year, the level of inputs is low, calf mortality is high, and the age of sale is late. (Carrying capacity for the land was 3.0 hectares per animal 3 years of age and older, 2.55 hectares per animal 2–3 years of age, 1.95 hectares per animal 1–2 years of age, and 1.35 hectares per animal from weaning to 1 year of age). With closer attention to breeding and care of the cows, the calf crop increases to 50%. The total herd inventory also increases but the number of cows (3 years and older) is reduced from 200 to 170. Gross income rises by nearly 23%, which seems encouraging, but when the increased returns are matched against the possible need of additional labor to care for the extra calves and perhaps the purchase of additional sires to cover the herd in a restricted breeding season, the incentive may not be attractive at all.

Table 19.2 is another example of a seemingly attractive way of increasing production by introducing one change. Here the objective is to sell animals at an earlier age in order to reduce risks of losses prior to sale and to build up cow numbers, thereby gaining returns through an increased turnover rate. In the Table, 55 months repre-

TABLE 19 1
Expected changes in herd makeup, number of marketable animals, and gross income per year from 1200 hectares of grazing land when calving percentage is increased from 35 to 50% per annum

	Calving %	
	35	*50*
HERD MAKEUP		
Cows (3 years and older)	200	170
Number of animals in other age groups		
4–5 years	45	54
3–4 years	46	56
2–3 years	47	58
1–2 years	50	61
8 months–1 year	53	64
0–8 months	56	68
Total all ages	497	531
GROSS RETURNS		
Number sold/year[a]	34	44
Average weight at sale (kg)	400	400
Gross income/year ($US)	4,760	6,160
Extraction rate/year (%)	6 8	8 7
Gross returns/hectare ($US)	3 97	5 13
BASIC VALUES FOR ESTIMATES		
Calf mortality 0–3 months (%)	20	20
Animal losses 3 months—sale (%)	20	18
Cow replacement /year at 12%	24	20
Price/kg live weight ($US)	35	35

[a]Taken from 4–5 year group minus 12% cow replacements required plus salvage value of ½ of culled cows

sents the original age of sale, while 43 months means selling at the end of the wet season one year ahead of the 55 month stage, and 8 months means selling weaned calves. Efforts to improve calving percentage (35%) are not part of the program. Selling at one of the earlier ages will permit an increase in cow and total herd numbers. Extraction rate will also rise. These are good points to present to potential users, especially since the recommendations do not project a rise in capital investments. But there may be some increase in labor needs when selling at 8 months due to the number of times the herd will need handling. Gross income will rise 6 2% by selling at 43 months but will decline 19% from the 55 month level if sales are made at 8

TABLE 19.2
Expected changes in cow numbers (cows 3 years and over), number of marketable animals, and gross income per year from 1200 hectares of grazing land when the age of marketing is reduced from the traditional 55 months.

	Age of Sale (months)		
	55	43	8
HERD INVENTORY			
Cows (3 years and older)	200	215	265
Number of animals in other age groups			
4–5 years	45	22	32
3–4 years	46	50	34
2–3 years	47	52	36
1–2 years	50	54	40
8 mo–1 year	53	56	71
0–8 months	56	60	75
Total all ages	497	509	553
GROSS RETURNS			
Number sold/year	34[a]	41[b]	47[c]
Average weight at sale (kg)	400	330	150
Gross income/year ($US)	4,760	5,054	3,868
Extraction rate/year (%)	6.8	8.1	8.5
Gross returns/hectare ($US)	3.97	4.21	3.22
BASIC VALUES FOR ESTIMATES			
Calving percent/year	35	35	35
Calf mortality 0–3 months (%)	20	20	20
Animal losses 3 months – sale (%)	20	18	5
Cow losses/year (%)	12	12	12
Price/kg live weight ($US)	.35	.35	.35

[a] 4–5 year age group minus animals needed that year as replacements
[b] Includes 28 steers near 43 months plus salvage value of ½ of cows (13) lost each year from sterility and physical defects
[c] Includes 31 young stock plus salvage value of 16 culled cows

months. (The numbers shown in the age categories between 1 and 5 years are the needed female replacements). The sale at much lighter weights and the need for more heifers to keep a larger cow herd reduce income. This further illustrates how what might appear on the surface as an interesting proposition might not be acceptable in practice.

The values in Table 19.3 relate to a "package of practices" on a 1200 hectare farm. Pastures and their management are improved to

TABLE 19 3
Expected changes in the number of animals available for sale from 1200 hectares of land with a combination of practices for improved feeding and management

	Age of Sale (months)			
	43	31	19	10
HERD INVENTORY				
Cows (3 years and older)	250	300	360	410
Number of animals in other age groups				
3–4 years	138			
2–3 years	140	166	72	82
1–2 years	142	168	204	82
8 month–1 year	144	170	206	240
0–8 months	147	175	210	240
Total all ages	961	979	1,052	1,054
GROSS RETURNS				
Number sold/year[a]	135	163	200	238
Average weight at sale (kg)	400	340	270	200
Gross income/year ($US)	18,900	20,594	21,994	22,260
Extraction rate/year (%)	14 0	16 6	19 0	29 2
Gross returns/hectare ($US)	15 75	17 16	18 33	18 55
BASIC VALUES FOR ESTIMATES[b]				
Calf mortality 0–3 months (%)	10	10	10	10
Animal losses 3 months–sale (%)	6	5	3	1
Cow replacement/year (%)[c]	20	20	20	20
Price/kg live weight ($US)	35	35	35	35

[a] Includes animals available for sale minus cow replacements plus salvage value of 95% of cows culled
[b] Calving percentage 65%/yr
[c] Includes 10% attrition due to disease, sterility, and physical injury, plus 10% culling

the point that the carrying capacity is about 1.5 hectares per animal 8 months of age and over instead of 3.0 hectares as in the two previous illustrations. Calf mortality from birth to 3 months is reduced from 20 to 10%, as are animal losses from 3 months of age until time of sale. Through a combination of inputs—better feed supplies, regulation of the breeding season, and animal care—the annual calving percentage rises to 65%. Cow replacements are increased from 12 to 20% in order to permit culling on performance in the cow herd. The receipts from the sale of cull cows is included in gross income.

The four columns in Table 19.3 depict the expected herd inventories and gross returns when the herd is operated for sale of animals near 43, 31, 19, or 10 months. This plan could be recom-

mended in an area with a 7–8 month wet season and a 4–5 month dry season, using grazing only. The adoption of the improved practices will permit nearly doubling the extraction rate in the two previous tables, and gross income is expected to rise fourfold or more. (Gross income is based on the sale of steers, possibly some culled heifers, and the salvage value of 95% of the cows culled each year). If the herd is operated to sell at 31 months of age or less, it can be reasonably projected that heifers will calve earlier—by 3 years of age—thereby boosting income. Operating to sell at 31, 19, and 10 months will give an expected rise in gross income of 9.0, 16.3, and 17.8%, respectively, over that for an operation selling at 43 months.

Taken at face value, it appears that the only way of really increasing the output of beef is by a "package of practices." For the long run it can be assumed this is the only approach that is worthwhile, particularly for programs requiring considerable governmental participation. On the other hand, the "single practice" approach may sometimes warrant consideration—e.g., when the operator owns the land; taxes are low or essentially nonexistent; certain facilities already exist, such as housing for labor; and the location of the farm is such that costs for improvements would be too high to undertake a program like that illustrated in Table 19.3. In these situations, many of which exist in remote areas of Latin America, the small increases realized from practices illustrated in Tables 19.1 and 19.2 may be attractive enough to operators for acceptance. However, investors are not likely to inaugurate new enterprises, and there is not likely to be a progressive expansion of the beef industry unless returns are reasonably good, as in Table 19.3.

Another potentially useful approach in economic planning is to show operators why income is low, to support the need for changes and attract new investors. Table 19.4 shows the changes in income per cow per year for various calving percentages and market prices. In general, there is a direct relationship between weight of the calf at weaning and calving percentage, hence as the calf crop decreases so does the weight per calf. Although the calf may not be sold until much later, this schedule can be used to derive estimated returns on investment per cow. It is readily evident that calvings of 60% or less will hardly give returns above depreciation on the cows.

Table 19.5 contains data on the estimated cost per year for keeping a beef cow in the lowlands of northern Colombia using unimproved grasslands at a rate of a cow and calf per 3 hectares. If the calving percentage is less than 60%, it is readily evident that the

TABLE 19 4
Possible income per cow for various calving percentages, body weights, and market pri

Weaning				
Percentage	*Wt/calf (kg)*	*Calf wt/cow in the herd (kg)*	*Returns with 3 prices ($US) kg*	
			0 28	*0 32*
90	200	180	50 40	57 60
80	200	160	44 80	51 20
70	180	126	35 28	40 32
60	160	96	26 88	30 72
50	150	75	21 00	24 00
35	140	49	13 72	15 68

TABLE 19 5
Estimated cost per year ($US) of keeping a beef cow in the lowland tropics of Latin America on unimproved grasslands (cow + calf/3 hectares) in minimum units of 200 to 400 hectares

	Charge/cow
Land value $35/ha at 10%	10 50
Corrals and fencing ($5/ha/10 yr)	1 50
Bull charge ($300/20 cows for 4 yr $124 resale)	2 20
Taxes (slaughter rights, sales, property)	4 00
Value of cow ($144 resale value $120 + duration of 4 yr)	6 00
Salt and minerals	0 96
Tools, saddles, horses ($120/400 ha)	0 30
Labor (2 men/yr $1200/400 ha)	1 50
Transportation to market	4 00
Total outlay	30 96
Interest on capital at 10%	3 10
Total cost/cow/yr	34 06

return per cow is submarginal according to Table 19 4. In this particular region calving percentages ranged from 35 to 50% per year. The operators managed to survive because they owned the land, paid few taxes, and did not buy bulls. Due to low direct costs, their real costs were around $17.00 per cow per year. Even so, this does not provide a very high return on investment and definitely would not attract new investors.

Table 19.6 shows the estimated annual cow costs where investments are rather high, such as might be required for the "package of

TABLE 19.6
Estimated annual cost ($US) of keeping a beef cow in the lowland tropics of Latin America on improved but unfertilized pasture (cow + calf per hectare) in minimum units of 200 to 400 hectares

	Charge/cow
Land value $160 at 10% interest	16 00
Pasture establishment and maintenance	8 00
Fencing ($80 for 10 yr duration)	0 80
Watering places ($80 for 10 yr)	0 80
Buildings and other improvements ($20/ha for 20 yr)	1 00
Bull charge ($400/20 cows for 4 yr: $160 salvage)	3 00
Taxes (slaughter rights, sales, property)	4 00
Value of cow ($144 with life of 4 yr. $120 salvage)	6 00
Salt and minerals	0 96
Medicines, insecticides, vaccines	1 60
Vehicles ($592/yr/400 ha)	1 48
Tools, saddles, horses ($120/400 ha)	0 30
Fuel and repairs ($600/400 ha)	1 60
Labor (2 men/yr $1,152/400 ha)	2 88
Transportation to market	4.00
Total outlay	52 42
Interest on capital at 10%	5 24
Total cost/cow/yr	57 66

Source Adapted from DeAlba, 1967

practices" (Table 19.3). The cost per cow is about 70% over that for Table 19.5. When the costs are raised, a calving percentage of 65% or better becomes mandatory.

Depicting two situations—the current one, as in Table 19.5, and the projected one, as in Table 19.6—could be useful in the planning stages to insure that all the increased inputs required are considered and in the field to illustrate several of the reasons why incomes are low as well as what specific changes are required for marked improvement.

The Tables cited have not yet been verified with adequate economic data. Nevertheless, they serve to illustrate the central point that planners should carefully evaluate their projected programs in relation to economic feasibility. This is a vital part of the motivation stressed in the earlier sections. These illustrations also indicate the need for assistance from a professional economist on the "planning team."

REQUISITES FOR LIVESTOCK DEVELOPMENT

In planning livestock programs the projections for change should be carefully examined relative to conditions for "payoff." In outlining the conditions for livestock development, there is the temptation to set forth a catalog of musts. There must be production oriented research, improvements in education, communications, transportation, marketing, etc. These are certainly important, but in the initial stages of program development the ranking of the musts for payoff are (1) incentive or motivation, (2) stability of government, (3) credit institutions, (4) research programs, and (5) expansion of education.

Research and education often appear at the top of the listing, thus the order of priority is unconventional. Its strength lies in the premise that once livestock production, as well as other agricultural enterprises, gathers momentum, the political initiative for sustaining the forward motion will be created by pressing demands for advancements in technology, more input supplies, and satisfactory marketing conditions. As already indicated there can be no change without incentive, and incentive depends largely on economic conditions.

Closely related to motivation is the need for political stability. The degree of risk rises in unstable situations, and this further deters investment. Similarly, credit institutions must have a stable environment to provide capital at reasonable rates of interest. When this condition does not exist, interest rates are all out of proportion.

Although successful plant agriculture usually requires technology that has been tested under local conditions, animal agriculture can sometimes be developed without it. For instance, the organisms that cause mastitis in lactating cows are numerous, but they are not grossly different throughout the world. Certainly, the same can be said for the principles of animal breeding and the approximate amounts of energy inputs needed by animals.

While literacy is highly desirable, its absence is not a complete inhibitor to livestock production. No matter what the level of literacy, farmers will respond to most new ideas if they can be convinced by practical demonstration that changes will bring substantial profits.

Planners should not depend wholly on governments to bring about changes in livestock production. Governments are notoriously inflexible in their responses to rapidly developing opportunities. Private business, given encouragement and left to function with a minimum of impediments, responds better. Therefore, the most productive role for government is underwriting those basic facilities

and services that require sustained investments over long periods of time—investments that will bring about an increasing flow of incentives to attract private capital into the livestock sector.

PROGRAMING FOR ASSISTANCE TO SMALL OPERATORS

Earlier it was suggested that in countries where food resources are restricted animal production should be maximized by establishing or improving the efficiency of large enterprises. However, complete concentration on large enterprises would do little to improve the lot of the peasants or maximize total economic development. The existing pressures for broader distribution of lands for agriculture in countries where a very small segment of the population controls the vast majority of the land resources cannot be ignored. Also if we accept the hypothesis that economic development is a phenomena of man brought about through his capabilities to organize and motivate and his ability to do things with his hands, then attention and assistance to all levels of farm operations is needed to make the most of economic development.

Of course, there are some monumental illustrations of what might be considered failures in programs for small farms if results are judged on the basis of return on investment, e.g., the experience with dairying in Trinidad cited earlier. An equally unsuccessful venture comes from attempts in northern Colombia to increase beef production on small holdings. Colombian farmers with small holdings have been encouraged to accept loans to purchase cattle with the intent of improving total output per farm.

The Colombian farmer has about 6 hectares of land. He lives on the land and has one or more small plots of potatoes, vegetables, or cassava along with some fruit trees. The total cultivated land is about 0.5 hectares worked entirely by hand, with the remainder left to native grasses. When the fertility of the cultivated plot declines, a new area is opened, thus an operation of shifting cultivation. These farmers were encouraged to obtain loans to buy three cows of calving age, because these could be expected to provide early returns. The average experience was that two of the cows produced calves during the first year and the third one calved a year later, but at the end of seven years the farmer had contributed only about four animals to the country's meat supplies. This was because the land and grass resources were restricted to the holdings and the animals produced had

little or no value at the market until they reached 400 kg weight at 4 to 5 years of age The farmers were thus forced to sell the cows purchased originally in order to have enough feed to grow out the young animals to an acceptable size for the market If these small operators could have sold their calves at a reasonable price soon after weaning to other farmers for growing out, the program could have been successful This example illustrates a deficiency in programing Nevertheless, the basic objective of assistance through provision of credit was sound

An excellent illustration of increased livestock production on small farms is provided by the Italian commune Borgo a Mozzano (Virone *et al*, 1966) Although the area lies outside the N-S 30° latitudes, the difficulties encountered were similar to those of warm climates This program involved a group of sixteen hamlets or villages Technical assistance in the form of advice was started in 1954, and by 1965 gross salable agricultural production was increased 136% In the beginning livestock products contributed less than 30% of total gross product, but in 1965 livestock—chiefly cattle—contributed 38% of the total The cattle were kept at the rate of about four head per farm The first problem tackled was marketing A dairy cooperative was set up to centralize processing and to control quality of milk and cheese Gradually farmers accepted the need to record the performance of their animals, and major diseases were controlled by elimination of sick animals, a policy made attractive to owners by support from insurance policies Feed costs were reduced by cooperative buying and forage supplies were expanded through the use of new species The traditional cattle breed was gradually replaced with more productive stock Apart from helping to keep labor more fully employed through the year and supplying a steady income, cattle provided a means of utilizing and manuring forage plants whose use in crop rotation benefited other crops

The salient feature of this program was development of cooperation, which led to generation of the necessary capital to bring about the improvements in production and income Outside help consisted principally of leadership in introducing technology that produced the incentives and motivation for the farmers

Probably the most spectacular development of livestock production in a rural area is the Karia District Cooperative Milk Producer's Union Ltd, India, which is centered about 400 km north of Bombay This started as a village milk collection scheme in 1945 By 1969 there were about 115,000 members in some 550 villages (Kurien, 1970) The Union collects, processes, and dispatches about 100,000 liters of milk

daily in railtankers to Bombay (Khurody, 1967). The Union represent a cooperative developed through government agencies providin leadership and facilities. The need for providing facilities is ex plained by Kurien: "Our experience in Karia District was that w could not fulfill our milk producers' objectives until we had proces ing and marketing facilities which enabled us to handle all the mil which our producers wanted to sell all the year round." Seasonal in balances in supply and demand, caused the cooperative to develo facilities for handling milk products—that is, dry solids as well a whole milk. The Union now maintains a feed mill, animal healt services, and record keeping for its members.

Successful cooperatives have been established elsewhere i India to promote dairy production among small farmers. Further e pansion of dairy cooperatives is underway through "Operation Flood The plan calls for resettling up to 100,000 city kept milk animals in rural milk sheds where their milk will be collected and process for urban centers. It will also organize direct procurement of mi from the owners of about two million milk animals in rural milk shec The main purpose of the program is to aid in the economic develo ment of the rural areas. The leadership will be provided by the Indi Dairy Cooperation. The objective is to have an efficient procureme organization that the farmers can trust. Previous experiences in Inc have shown that a trusted procurement organization must exist befc farmers will invest to increase milk production. Agents of the procu ment organization will be in direct contact with farmers twice dai therefore, the organization should be able to build confidence a react to problems of farmers (Kurien, 1970).

Other cooperatives with varying degrees of technical assistan and capital inputs are developing in numerous areas throughout t warm climate region. Many are resettlement schemes involving la reform, while others follow the pattern for the Karia District and t Borgo a Mozzano plans in working with farmers already keeping li stock.

Some planners, such as Gondim (1964), contend that all the sm farmer needs is information and a demonstration of what can be do He claimed that after a simple demonstration of increased anir gains of 60% on grazing Brazilian savannah, following the correct of simple soil mineral deficiencies with an application of cobalt a phosphorus, the practice received wide acceptance. Others ha conveyed the impression that a few demonstrations of dipping ca for the control of ticks leads to rapid acceptance of the practice tribal herders in areas of Uganda and Kenya.

From the foregoing reports it is readily evident no fixed model can be recommended for assisting small farmers It is impossible to argue with success no matter what the approach may be But in general it appears that the best programs involve development of cooperation or, put another way, the helping of farmers to help themselves Motivation seems a high priority factor too The successful programs have focused on assistance in stabilizing markets as the main motivator for change Development of marketing procedures usually requires the creation of cooperatives of one type or another In fact we can assume that some type of cooperative is necessary to get the best job done for small farmers It can serve many of their needs, including animal improvement When animals are kept in small units, the possibilities for genetic improvement by selection within the herd or flock are extremely limited As pointed out in Chapter 10, state operated seedstock herds are needed to distribute superior males Cooperatives afford a means of supporting area programs of this nature

PROSPECTS FOR LIVESTOCK DEVELOPMENT

Those attempting to expand and improve livestock production must prepare their case well, or there will be little or no change They will have to confront the question How can nations that are experiencing pressures of increased population and lessening of per capita food afford the inefficiencies of food production through livestock? The comparison in Figure 19 1 of the number of days of protein requirements for a moderately active man that can be produced on 0 4 hectares illustrates that livestock are relatively low in efficiency of protein production per unit of land in comparison to white rice and soybeans With the world population expected to double in about 35 years, many believe that animal protein will become a dietary luxury Animals also compete directly with man for much of his food protein coming from plants, animal production requires another step involving additional inputs, risks, and time, and income levels may not permit the purchase of animal proteins in many regions of the world Furthermore, under current systems of management in some areas, livestock are preventing conservation practices needed to alleviate depletion of soil reserves, for example, in northern Africa and southern Asia the vegetative cover on 0 25 million hectares is almost completely inundated annually by nomadic flocks of sheep and goats

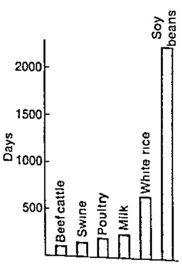

FIGURE 19.1
Number of days of protein requirement for a moderately active man that can be supplied from 0.4 hectare of land with six different crops. (Data from FAO, 1966).

Factors Favoring Animal Production

Whether we accept these projections on the future food supplies or not, they are possibilities that we must face when we consider the future role of animal products. However, we need not succumb to the pessimistic view on the future of livestock as our case is a good one and perhaps in some respects stronger for the tropical areas than for some portions of the temperate regions. The possibilities for expansion of animal protein production in Latin America, Africa, the Near East, and southeast Asia are very good. The problem is more complex in India and Pakistan, but even in these countries substantial increases are possible.

Phillips (1969) groups the factors favorable to animal production into six categories: (1) the nutritional requirements of expanding populations, (2) the special qualities of animal products for human needs, (3) the need of animals as sources of power, (4) the importance of animals in maintaining soil fertility and in soil and water conservation, (5) the great flexibility of animals as convertors of materials into useful products, and (6) the social forces that favor utilization of animal products.

Putting aside the question of how the needs for food in the future can be met, the existence of the question is a major force favoring increases in animal production. The fact that animal products rank high among the dietary preferences of most of the world's peoples is also a favorable factor. Animal products are tasty and they are more easily digested and contain better balanced nutrients than plant products.

Even though synthetic fibers have come into wide use, animal fibers have qualities that make them highly desirable for clothing and for other fabrics. Hence, whether animal fiber serves as the primary product or a secondary product, fiber production is a factor favoring animal production. Often we tend to overlook the importance of animal products other than food or fiber that serve our needs. These include leather, bristles for brushes, pharmaceutical preparations from animal glands, and the end products of the processing of livestock products such as glue and gelatin or blood and bone meals. All these and numerous other by-products would be difficult to replace.

Although machinery, such as the tractor, is becoming increasingly important in agriculture, animal power is still depended upon for over 90% of the farm power in much of Africa, southeast Asia, and Latin America. There remain many problems hindering the achievement of anything like complete mechanization in these regions, including the size of farms, the costs of mechanization and fuel, and the abundance of manpower; therefore, the draft animal will be an important factor in the agriculture of these regions for some time. And, of course, animals are also popular for recreation.

In the U.S. the disposal of animal wastes has become a problem in large, drylot feeding operations; but in the warm climates animal manure is useful as fertilizer, and will no doubt continue in use until commercial fertilizer plants become widespread and transportation is greatly expanded.

The flexibility of animals as transformers of feed into usable products is among our major assets, and with developing technology will become even more important. Forages make up a large proportion of the ration for livestock. About 70% of the protein for the average dairy cow in the U.S. is obtained from forages. An average beef animal gets 60% of its protein from forages, and sheep from 80 to 90%. In the warm climate region these proportions would be even higher. Furthermore, forages are often grown on lands that are submarginal or entirely unsuitable for producing other crops. All livestock use feeds that are by-products of the processing of human food items, e.g., wheat mill feed, rice bran, and molasses. In the harvesting of crops, certain products are inedible for direct human consumption but can be converted to human foods through livestock.

Animals have a wider capability than plants for fitting into different environments. With some modification of the natural environment most livestock will survive and give some performance. The broad variation in environmental adaptation favors livestock.

Another aspect often receiving inappropriate consideration in assessing the contribution of livestock in certain regions is the lack

of capital for mass production of crops and the necessary transportation and storage systems for effective distribution. Vast areas of the low latitudes—e.g., the southern half of Venezuela, the eastern half of Colombia, northwestern Brazil, the eastern portions of Peru and Equador, and the part of Australia lying north of the Tropic of Capricorn—are almost entirely without roads or railroads. The only significant contribution these areas can make to food supplies is through livestock, principally cattle and sheep. After making use of the grasslands, these species can be moved directly to market or to intermediate points on foot. Until roadways penetrate these areas, the production of agricultural commodities for other than household consumption is not economically feasible.

Even though livestock normally do not provide the same returns per unit of land as crops, in semi-arid regions cattle or sheep may give relatively high returns for the cost of water, as shown by Upton's study (1968) of the relative merits of cattle and irrigated crops in Botswana.

The factors favoring livestock, coupled with man's ingenuity in meeting his needs, should make it possible for animals to maintain and even increase their present important role in the world's food production.

Potential for Livestock in Warm Climates

In summary, livestock production is difficult but not impossible in the lower elevations of the N-S 30° latitudes. Whether the overall problems created by the natural environment are greater or less than for, say the 40–50° north latitudes, is subject to conjecture. The analogous seasonal fluctuations in quality and quantity of natural grasslands portrayed in Figure 1.3 suggest that the problems in the temperate, subtropical, and tropical regions are similar in many respects. That the output per animal in the warm climates is much lower than in temperate areas is undisputed. Whether this contrast will continue to exist is seemingly dependent upon how rapidly measures are taken to enhance the rate of output in the warm climate region. The level of efficiency for livestock in the region will continue low and total output will continue at the very modest level of 2.0 to 2.5% per year until more active, well planned programs are undertaken.

There is strong evidence that the genetic capability of many breeds of livestock considered native to the N-S 30° latitudes is so low that they are incapable of responding to improved environmental conditions, such as greater feed supplies. This is significant because

nutrition is the most important of the environmental factors limiting production There is even doubt about the value of native cattle for milk production under improved environmental conditions But there is equally strong evidence that the utility of improved European breeds of cattle for the region is limited to at least some extent by precisely the same genetic differences that resulted from their intensive selection for performance under temperate conditions The basic principles of animal breeding appear to apply equally well to both indigenous livestock and those from temperate regions, therefore, it becomes a matter of expanding or developing programs which will implement wider use of the principles of improved breeding Though generally not conclusive, a review of experiments on crossbreeding indicates that much wider use could be made of this system of breeding as the most rapid means of overcoming some of the serious deficiencies in the native stock, especially temperament in relation to response to the milking process Of course, there is an urgent need for specifying managerial systems in different climatic zones—hot, dry, and hot, humid—which will permit profitable use of improved stocks in the near future

Milk production in the N-S 30° region requires basic investments in buildings, land, veterinary services, etc and these investments are needed irrespective of the breed type used The genetic potential for milk production in a few indigenous strains will pay a modest interest on some investment, but under reasonably improved environmental conditions, crossbreds or high grade European types will be needed

There is a need for stratification in beef cattle production in the region In many locations, cattle will have to continue to survive under severe environments, whereas, in others there is an increasing possibility of utilizing surplus grains, by-products, and improved pastures for more intensive operations Under some management systems and in some environments, selection may have to await improved conditions while in others, intensive production and selection for better growth rates are now possible Environments need evaluation and defining in terms of stocking rates as well as climatic conditions

Encouraged by the successful recent introduction of new plant varieties and the performance of some crossbred animals, a few countries contemplate a large utilization of imported stock Much attention will be needed to secure adequate management for improved livestock, the human factor may be more important here than the environment

Exceptionally long calving intervals are a primary contributing factor to reduced herd efficiency in cattle herds Problems of disease

and malnutrition are serious retarding factors, but even when these factors are not limiting, many cattle exhibit prolonged periods of anestrus. Where estrus does occur it is likely to be of short duration and is often followed by ovulation failure. A high percentage of the eggs that are fertilized fail to develop normally. These events indicate abnormal secretion rates of gonadotrophic hormones. It is important to determine whether this is the case and if so to identify the environmental factors responsible for hormonal imbalances. Preliminary evidence indicates that hormonal therapy will be useful in obtaining a stronger expression of estrus, followed by ovulation and higher conception rates.

The use of artificial breeding offers promise in improvement of cattle in tropical areas, but its success depends upon training personnel in methods of heat detection and some changes in methods of handling semen.

The potential for improving feed supplies, both in quality and quantity, is probably the greatest challenge facing farmers in tropical areas. As pointed out in Chapters 6 and 7 the possibilities are great. Shortages of high protein feeds are a major problem but the returns from improved grasses under heavy fertilization rates in Puerto Rico and elsewhere demonstrate what can be done. The use of grass-legume mixes to enhance total production of feed and extension of the grazing season in Australia point to some of the steps that can be taken in this direction. The use of nonprotein nitrogen to supplement rations for ruminants is another potential yet unrealized.

Recent experiences in Colombia with several varieties of cassava with three to five times higher protein levels and the use of corn with the opaque-2 gene offer promise of helping solve protein shortages. Research from Cuba indicates that much wider use of molasses and sugar are warranted for both cattle and swine production (Preston and Willis, 1969). The most encouraging thing about expanded use of products from sugarcane is that tropical areas have the potential for producing more readily available energy per unit of land with this crop than temperate regions. Of major importance is that this can be achieved by means of technology now possessed in tropical areas.

It is already recognized that certain intensive husbandry systems of poultry and swine production are similar throughout the world and that for such enterprises satisfactory stocks are available at reasonable costs. Hence, the expansion of the swine and poultry industries is closely tied to the capabilities of providing suitable supplies of feed and the expansion of markets.

The prospects for the expansion of sheep and goat husbandry are good. A number of the breeds of each species appear suitable for

selective improvement, especially with respect to meat and milk production. Programs for improving marketing methods and systems for better preparation of the animals through periods of good levels of feeding prior to marketing are highly desirable.

Much greater attention must be given to programs for controlling diseases and parasites in order to reduce the present intolerable levels of mortality and morbidity.

Farmers must also be helped to acquire the necessary technical and managerial skills. The speed with which this can be done will depend on the extent of local services. Although the outlook for such educational programs has generally been poor, the future prospects are much better because many of the scientific principles on which tropical livestock development policies ought to be based have come to light for the first time very recently. This greatly enhances the prospects that livestock industries can be developed to help meet food demands and in so doing contribute to the overall economy, rather than continuing to be parasitic upon it.

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